NONRESIDENT TRAINING COURSE

April 1999

Aerographer's Mate

Module 3—Environmental Satellites and Weather Radar

NAVEDTRA 14271

NOTICE

Pages 2-35, 2-39, 2-41, 2-42, 2-44, 2-45, 2-47, 2-53, 2-54 must be printed on a **COLOR** printer.

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Although the words "he," "him," and "his" are used sparingly in this course to enhance communication, they are not intended to be gender driven or to affront or discriminate against anyone.

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PREFACE

By enrolling in this self-study course, you have demonstrated a desire to improve yourself and the Navy. Remember, however, this self-study course is only one part of the total Navy training program. Practical experience, schools, selected reading, and your desire to succeed are also necessary to successfully round out a fully meaningful training program.

THE COURSE: This self-study course is organized into subject matter areas, each containing learning objectives to help you determine what you should learn along with text and illustrations to help you understand the information. The subject matter reflects day-to-day requirements and experiences of personnel in the rating or skill area. It also reflects guidance provided by Enlisted Community Managers (ECMs) and other senior personnel, technical references, instructions, etc., and either the occupational or naval standards, which are listed in the *Manual of Navy Enlisted Manpower Personnel Classifications and Occupational Standards*, NAVPERS 18068.

THE QUESTIONS: The questions that appear in this course are designed to help you understand the material in the text.

VALUE: In completing this course, you will improve your military and professional knowledge. Importantly, it can also help you study for the Navy-wide advancement in rate examination. If you are studying and discover a reference in the text to another publication for further information, look it up.

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Sailor's Creed

"I am a United States Sailor.

I will support and defend the Constitution of the United States of America and I will obey the orders of those appointed over me.

I represent the fighting spirit of the Navy and those who have gone before me to defend freedom and democracy around the world.

I proudly serve my country's Navy combat team with honor, courage and commitment.

I am committed to excellence and the fair treatment of all."

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Nonresident Training Course Follows The Index

SUMMARY OF THE AEROGRAPHER'S MATE TRAINING SERIES

The following modules of the AG training series are available:

AG MODULE 1, NAVEDTRA 14269, *Surface Weather Observations*

This module covers the basic procedures that are involved with conducting surface weather observations. It begins with a discussion of surface observation elements, followed by a description of primary and backup observation equipment that is used aboard ships and at shore stations. Module 1 also includes a complete explanation of how to record and encode surface METAR observations using WMO and NAVMETOCCOM guidelines. The module concludes with a description of WMO plotting models and procedures.

AG MODULE 2, NAVEDTRA 14270, *Miscellaneous Observations and Codes*

This module concentrates on the observation procedures, equipment, and codes associated with upper-air observations and bathythermograph observations. Module 2 also discusses aviation weather codes, such as TAFs and PIREPs, and includes a chapter on surf observation procedures. Radiological fallout and chemical contamination plotting procedures are also explained.

AG MODULE 3, NAVEDTRA 14271, *Environmentul Satellites and Weather Radar*

This module describes the various type of environmental satellites, satellite imagery, and associated terminology. It also discusses satellite receiving equipment. In addition, Module 3 contains information on the Weather Surveillance Radar-1988 Doppler (WSR-88D). It includes a discussion of electromagnetic energy and radar propagation theory, and explains the basic principles of Doppler radar. The module also describes the configuration and operation of the WSR-88D, as well as WSR-88D products.

AG MODULE 4, NAVEDTRA 14272, *Environmental Communications and Administration*

This module covers several of the most widely used environmental communications systems within the METOC community. It also describes the software programs and products associated with these systems. The module concludes with a discussion of basic administration procedures.

NOTE

Additional modules of the AG training series are in development. Check the NETPDTC website for details at http://www.cnet.navy.mil/netpdtc/nac/neas.htm. For ordering information, check NAVEDTRA 12061, Catalog of Nonresident Training Courses, which is also available on the NETPDTC website.

SAFETY PRECAUTIONS

Safety is a paramount concern for all personnel. Many of the Naval Ship's Technical Manuals, manufacturer's technical manuals, and every Planned Maintenance System (PMS) maintenance requirement card (MRC) include safety precautions. Additionally, OPNAVINST 5100.19 (series), *Naval Occupational Safety and Health (NAVOSH) Program Manual for Forces Afloat,* and OPNAVINST 5100.23 (series), *NAVOSH Program Manual,* provide safety and occupational health information. The safety precautions are for your protection and to protect equipment.

During equipment operation and preventive or corrective maintenance, the procedures may call for personal protective equipment (PPE), such as goggles, gloves, safety shoes, hard hats, hearing protection, and respirators. When specified, your use of PPE is mandatory. You must select PPE appropriate for the job since the equipment is manufactured and approved for different levels of protection. If the procedure does not specify the PPE, and you aren't sure, ask your safety officer.

Most machinery, spaces, and tools requiring you to wear hearing protection are posted with hazardous noise signs or labels. Eye hazardous areas requiring you to wear goggles or safety glasses are also posted. In areas where corrosive chemicals are mixed or used, an emergency eyewash station must be installed.

All lubricating agents, oil, cleaning material, and chemicals used in maintenance and repair are hazardous materials. Examples of hazardous materials are gasoline, coal distillates, and asphalt. Gasoline contains a small amount of lead and other toxic compounds. Ingestion of gasoline can cause lead poisoning. Coal distillates, such as benzene or naphthalene in benzol, are suspected carcinogens. Avoid all skin contact and do not inhale the vapors and gases from these distillates. Asphalt contains components suspected of causing cancer. Anyone handling asphalt must be trained to handle it in a safe manner.

Hazardous materials require careful handling, storage, and disposal. PMS documentation provides hazard warnings or refers the maintenance man to the Hazardous Materials User's Guide. Material Safety Data Sheets (MSDS) also provide safety precautions for hazardous materials. All commands are required to have an MSDS for each hazardous material they have in their inventory. You must be familiar with the dangers associated with the hazardous materials you use in your work. Additional information is available from you command's *Hazardous Material Coordinator.* OPNAVINST 4110.2 (series), *Hazardous Material Control and Management,* contains detailed information on the hazardous material program.

Recent legislation and updated Navy directives implemented tighter constraints on environmental pollution and hazardous waste disposal. OPNAVINST 5090.1 (series), *Environmental and Natural Resources Program Manual,* provides detailed information. Your command must comply with federal, state, and local environmental regulations during any type of construction and demolition. Your supervisor will provide training on environmental compliance.

Cautions and warnings of potentially hazardous situations or conditions are highlighted, where needed, in each chapter of this TRAMAN. Remember to be safety conscious at all times.

INSTRUCTIONS FOR TAKING THE COURSE

ASSIGNMENTS

The text pages that you are to study are listed at the beginning of each assignment. Study these pages carefully before attempting to answer the questions. Pay close attention to tables and illustrations and read the learning objectives. The learning objectives state what you should be able to do after studying the material. Answering the questions correctly helps you accomplish the objectives.

SELECTING YOUR ANSWERS

Read each question carefully, then select the BEST answer. You may refer freely to the text. The answers must be the result of your own work and decisions. You are prohibited from referring to or copying the answers of others and from giving answers to anyone else taking the course.

SUBMITTING YOUR ASSIGNMENTS

To have your assignments graded, you must be enrolled in the course with the Nonresident Training Course Administration Branch at the Naval Education and Training Professional Development and Technology Center (NETPDTC). Following enrollment, there are two ways of having your assignments graded: (1) use the Internet to submit your assignments as you complete them, or (2) send all the assignments at one time by mail to NETPDTC.

Grading on the Internet: Advantages to Internet grading are:

- you may submit your answers as soon as you complete an assignment, and
- you get your results faster; usually by the next working day (approximately 24 hours).

In addition to receiving grade results for each assignment, you will receive course completion confirmation once you have completed all the assignments. To submit your assignment answers via the Internet, go to:

http://courses.cnet.navy.mil

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NETPDTC N331
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PENSACOLA FL 32559-5000

Answer Sheets: All courses include one "scannable" answer sheet for each assignment. These answer sheets are preprinted with your SSN, name, assignment number, and course number. Explanations for completing the answer sheets are on the answer sheet.

Do not use answer sheet reproductions: Use only the original answer sheets that we provide—reproductions will not work with our scanning equipment and cannot be processed.

Follow the instructions for marking your answers on the answer sheet. Be sure that blocks 1, 2, and 3 are filled in correctly. This information is necessary for your course to be properly processed and for you to receive credit for your work.

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Courses must be completed within 12 months from the date of enrollment. This includes time required to resubmit failed assignments.

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If your overall course score is 3.2 or higher, you will pass the course and will not be required to resubmit assignments. Once your assignments have been graded you will receive course completion confirmation.

If you receive less than a 3.2 on any assignment and your overall course score is below 3.2, you will be given the opportunity to resubmit failed assignments. **You may resubmit failed assignments only once.** Internet students will receive notification when they have failed an assignment--they may then resubmit failed assignments on the web site. Internet students may view and print results for failed assignments from the web site. Students who submit by mail will receive a failing result letter and a new answer sheet for resubmission of each failed assignment.

COMPLETION CONFIRMATION

After successfully completing this course, you will receive a letter of completion.

ERRATA

Errata are used to correct minor errors or delete obsolete information in a course. Errata may also be used to provide instructions to the student. If a course has an errata, it will be included as the first page(s) after the front cover. Errata for all courses can be accessed and viewed/downloaded at:

http://www.cnet.navy.mil/netpdtc/nac/neas.htm

STUDENT FEEDBACK QUESTIONS

We value your suggestions, questions, and criticisms on our courses. If you would like to communicate with us regarding this course, we encourage you, if possible, to use e-mail. If you write or fax, please use a copy of the Student Comment form that follows this page.

For subject matter questions:

E-mail: n315.products@cnet.navy.mil
Phone: Comm: (850) 452-1001, Ext. 1713
DSN: 922-1001, Ext. 1713
FAX: (850) 452-1370
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Address: COMMANDING OFFICER
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For enrollment, shipping, grading, or completion letter questions

E-mail: fleetservices@cnet.navy.mil
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FAX: (850) 452-1370
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NAVAL RESERVE RETIREMENT CREDIT

If you are a member of the Naval Reserve, you will receive retirement points if you are authorized to receive them under current directives governing retirement of Naval Reserve personnel. For Naval Reserve retirement, this course is evaluated at 2 points. (Refer to *Administrative Procedures for Naval Reservists on Inactive Duty*, BUPERSINST 1001.39, for more information about retirement points.)

COURSE OBJECTIVES

In completing this nonresident training course, you will demonstrate a knowledge of the subject matter by correctly answering questions on the following subjects: environmental satellite and weather radar.

Student Comments

Course Title: *Aerographer's Mate, Module 3—Environmental Satellites and Weather Radar*

NAVEDTRA: 14271 **Date**: _____

We need some information about you:

Rate/Rank and Name: _____ SSN: _____ Command/Unit _____

Street Address: _____ City: _____ State/FPO: _____ Zip _____

Your comments, suggestions, etc.:

Privacy Act Statement: Under authority of Title 5, USC 301, information regarding your military status is requested in processing your comments and in preparing a reply. This information will not be divulged without written authorization to anyone other than those within DOD for official use in determining performance.

NETPDTC 1550/41 (Rev 4-00)

CHAPTER 1

ENVIRONMENTAL SATELLITES

INTRODUCTION

Satellite images, or pictorial representations of satellite-sensed information, are some of the most frequently used tools in the fields of meteorology and oceanography.

As a Navy or Marine Corps observer, one of your primary duties will be to acquire satellite imagery. You may also be required to process the imagery to better display features of interest to the analyst. Later, as you begin to analyze meteorological and oceanographic situations, you will use satellite imagery as one of your most important sources of information.

In this chapter, we begin with an explanation of some of the basic terminology used to describe satellite orbits and satellite tracking. Next, we introduce environmental satellite programs, and then describe the various types of environmental satellites and explain their purposes. We then discuss some of the most common types of satellite imagery, and acquaint you with a few basic imagery enhancement techniques. We complete the chapter by taking a brief look at some of the equipment and methods that you will use to acquire and process satellite imagery.

SATELLITE TERMINOLOGY

LEARNING OBJECTIVES: Define basic terminology used in relation to satellite orbits and satellite tracking.

Before you can effectively acquire and use satellite imagery, it is important that you become familiar with some basic satellite terminology.

Environmental satellites orbit the earth at various altitudes. Some environmental satellites operate lower than 800 kilometers (500 statute miles), while others operate as high as 35,800 kilometers (22,300 statute miles). To stay in orbit, lower altitude satellites must orbit faster than higher altitude satellites. As a result, satellites in orbit at 800 kilometers complete an orbit in a little over 100 minutes, while satellites in orbit at 35,800 kilometers require 24 hours to complete an orbit.

The inclination angle of a satellite's orbit is the angle the satellite's path makes as the satellite crosses the equator (fig. l-1). This term is usually referred to as the satellite *inclination.*

Satellites that have an inclination of 0 degrees circle the earth over the equator in an *equatorial orbit.* When a satellite in an equatorial orbit moves from west to east in the same direction that the earth rotates, its speed and altitude may be adjusted so that it is always located in a stable orbit over the same position on the equator. Satellites in these orbits are called *geostationary, earth-synchronous,* or *geosynchronous* since they are stationary relative to their position over the equator. Their fixed location provides continuous coverage of the same area over a 24-hour period.

As shown in figure 1-1, satellites with high orbital angles generally cross over the polar regions and are called polar-orbiting *satellites.* These satellites orbit the earth about 14 times a day and provide global coverage every 12 hours. A single orbit of a polar-orbiting satellite is composed of an *ascending node,* which is the period of time when the satellite is traveling from south toward the north, and a *descending node,* which is the period of time when the satellite is traveling from north toward the south.

The position directly under a satellite on the surface of the earth is called the satellite *subpoint* or *nadir,* while the track of the satellite subpoint along the surface of the earth is called the *satellite path.*

Now let's consider some additional terms used in satellite orbits and satellite tracking.

Because the earth rotates, each time a polar orbiting satellite crosses the equator, its position is further west than its position on the previous orbit. This change in position is called the *nodal increment* (fig. l-2). The total time it takes the satellite to complete an orbit is called the *nodal period.* The term *epoch* refers to a specific reference point in a satellite's orbit.

Most polar-orbiting environmental satellites use a nodal increment and a nodal period that keep pace with the rotation of the earth and keep the satellite path crossing the equator at the same local mean time

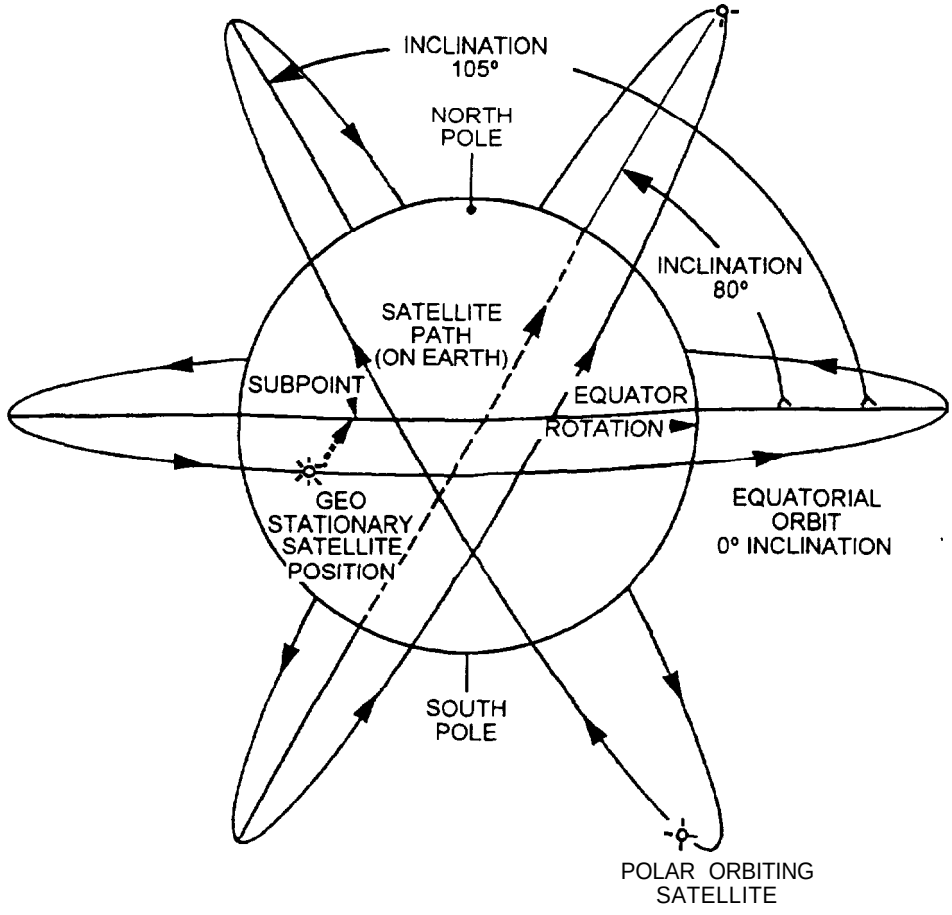


Figure 1-1.—Satellite inclination.

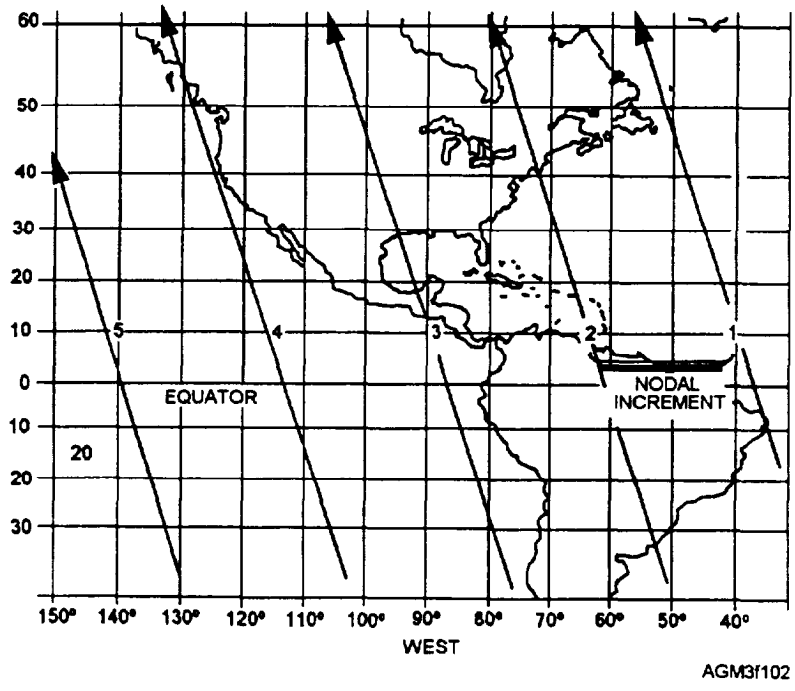


Figure 1-2.—Nodal increment–the westward change in position of a polar-orbiting satellite's path on earth on successive orbits.

(LMT) during each orbit. These types of orbits are called *sun-synchronous orbits*—they are synchronized with the movement of the sun across the earth's surface. For instance, an orbit may be calculated so that the satellite path crosses the equator on the descending node 2 hours after sunrise on each orbit.

The ascending and descending nodes may additionally be identified by the relative time of day, such as day-ascending, day-descending, night-ascending or night-descending node (fig. l-3). When an ascending node crosses the equator at a particular relative time, the descending node of the same orbit will cross the opposite side of the earth at a LMT about 12 hours opposite the ascending node LMT (plus one-half the nodal period). For example, if a satellite has a sun-synchronous orbit with a day-ascending node, then the descending node on the other side of the earth will be a night-descending node. To simplify the situation, only the relative time of day of the **ascending node** is referenced. For example, an environmental satellite known as a day-ascending satellite will always be over the sunlight portion of the earth when moving north, and it will always be over the dark side of the earth when traveling south. Night-ascending satellites will move northward over the dark side of the earth and southward over the sunlight side of the earth.

The National Oceanic and Atmospheric Administration (NOAA) normally maintains at least two operational polar-orbiting satellites. One is in a sun-synchronous morning orbit and the other is in a sun-synchronous afternoon orbit. Thus, each satellite provides two images every 24 hours (one day image and one night image), producing a total of four images a day over any given area.

When a satellite achieves orbit around the earth, the orbit is rarely a perfect circle. Most orbits are actually elliptical and they change over time because the earth is not a perfect sphere; it flattens over the poles and bulges near the equator. The gravitational pull of the earth, sun, and moon also plays a role. When the satellite comes closest to the earth, the satellite is said to be at *perigee*, and when it is farthest away from the earth, the satellite is said to be *apogee*. When at

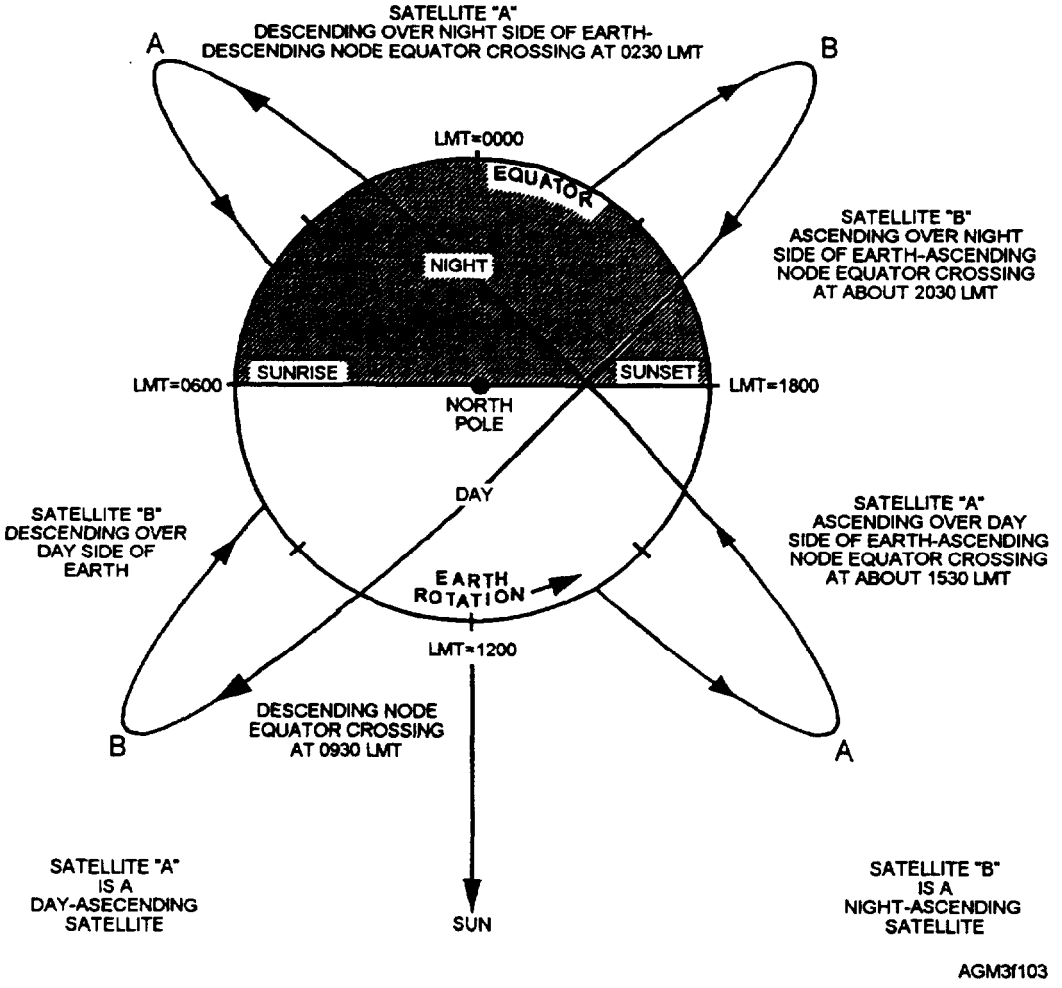


Figure 1-3.—Day-ascending and night-ascending polar orbits.

perigee, satellites move faster. When at apogee, satellites travel slower. This change in velocity complicates tracking of polar-orbiting satellites. For convenience and ease of orbit calculations, time is referenced to zero when a polar-orbiting satellite passes the equator northbound, and increases through a complete orbital period. Figure 1-4 illustrates the changes that can occur in the perigee and apogee of a satellite over time.

Most polar-orbiting satellites also have *anomalies* in their orbits. An anomaly in an orbit is any change or deviation from a perfectly stable orbit. Some anomalies are planned into an orbit so that the orbit will remain sun synchronous as earth revolves around the sun during the course of a year. Anomalies further complicate satellite orbital predictions.

REVIEW QUESTIONS

Q1. A satellite with an equatorial orbit would have an inclination angle of how many degrees?

Q2. What term is used for a satellite with an equatorial orbit moving with the same speed and direction as the earth?

Q3. What term is used to describe the period of time when a polar orbiting satellite is traveling south to north?

Q4. What is meant by the term "sun-synchronous" satellite?

Q5. If a satellite has an ascending node time of 1400 local, what would be the approximate descending node time at the same location?

Q6. What are the major factors that would cause changes in a satellites apogee and/or perigee position?

TYPES OF ENVIRONMENTAL SATELLITES

LEARNING OBJECTIVES: Recognize the various functions performed by environmental satellites. Identify the major satellite programs operated in the United States. Identify specific types of geostationary satellites, polar-orbiting satellites, DMSP satellites, and foreign satellites. Recognize the advantages and disadvantages of geostationary and polar-orbiting satellites.

The first meteorological satellite was launched in April of 1960, and was known as TIROS-1 (Television and InfraRed Observation Satellite). Since that time, numerous satellites with more advanced technology have been introduced, and today there are many different designs of meteorological and oceanographic satellites. Most of these satellites have a variety of sensor packages that survey electromagnetic energy at several different wavelengths.

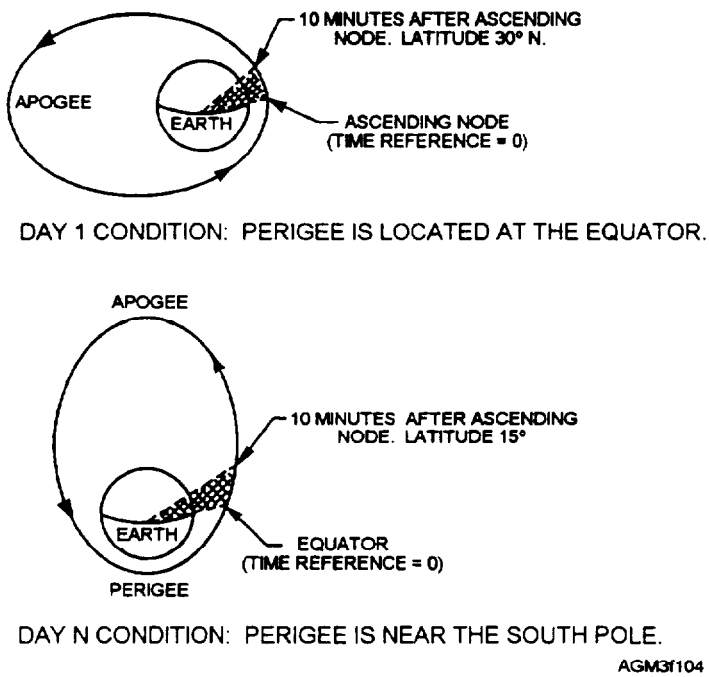


Figure 1-4.—Typical elliptical satellite orbit and changes in the orbital shape over a period of time.

Besides collecting imagery, most environmental satellites perform additional functions. Some satellites contain communications packages designed to receive and relay signals between earth stations and other satellites and to collect and relay observation reports from automatic observation sites or buoys. Some satellites carry search and rescue (SAR) beacon locators. More advanced satellites carry sophisticated instruments known as "atmospheric sounders." These systems use infrared and microwave energy to provide vertical temperature and moisture profiles of earth's atmosphere from the surface up to 30 miles. They also evaluate atmospheric stability. In addition, satellites can be used to measure a variety of other environmental parameters, such as sea surface temperature, wave height, snow/ice cover, low-level wind speed and direction, and ozone distribution. Although these functions are very important to meteorology and oceanography, you will not normally be involved in this type of data collection or data processing. In this module, we discuss only the differences in satellites that are important to you in acquiring satellite imagery.

In the United States, both the U.S. Department of Commerce and the U.S. Department of Defense operate meteorological satellite programs. The National Oceanic and Atmospheric Administration (NOAA), a division under the Department of Commerce, operates its satellite programs through the National Environmental Satellite, Data, and Information Service (NESDIS). Their primary meteorological satellite programs are the Geostationary Operational Environmental Satellite (GOES), and the Advanced Television InfraRed Observation Satellite-NOAA (ATN) polar-orbiter (also called a TIROS-N or NOAA satellite). Both systems are energized with solar power while in orbit. The Department of Defense oversees the Defense Meteorological Satellite Program, usually referred to as the DMSP.

GEOSTATIONARY SATELLITES

Geostationary satellites are placed at an altitude (35,800 km) where their orbital period exactly matches the rotation of the earth. The satellite sensors scan the earth in horizontal lines, starting near the North Pole and working down towards the South Pole. Geostationary satellites are ideal for making large-scale, frequent observations of a fixed geographical area centered on the equator. Thus, they are better suited to track rapidly moving large-scale disturbances in the atmosphere, or to look closely at small-scale or short-duration changes in the atmosphere. However, their distance from the earth limits the resolution of the imagery. In addition, these satellites do not "see" the poles at all, and to achieve global coverage of just the equatorial regions, a network of 5 to 6 geostationary satellites is required. Figure 1-5 shows atypical GOES satellite.

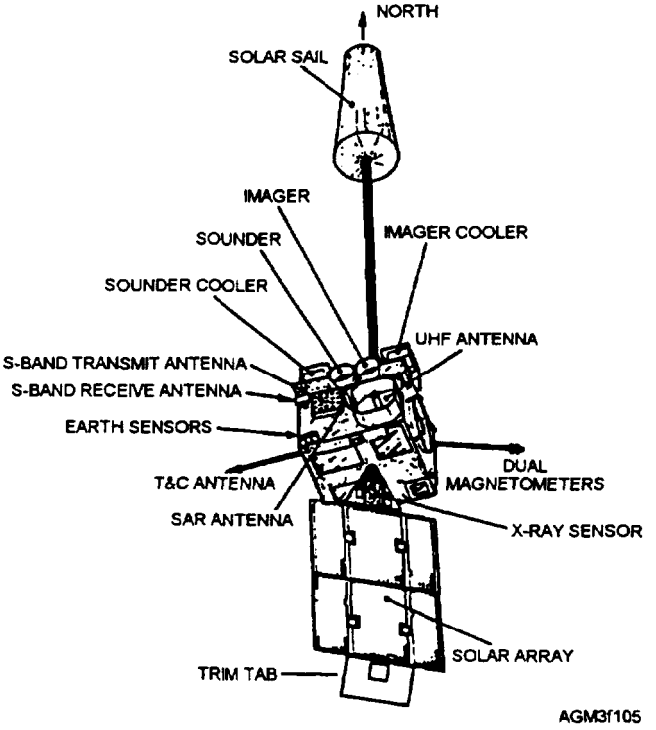


Figure 1-5.—GOES satellite.

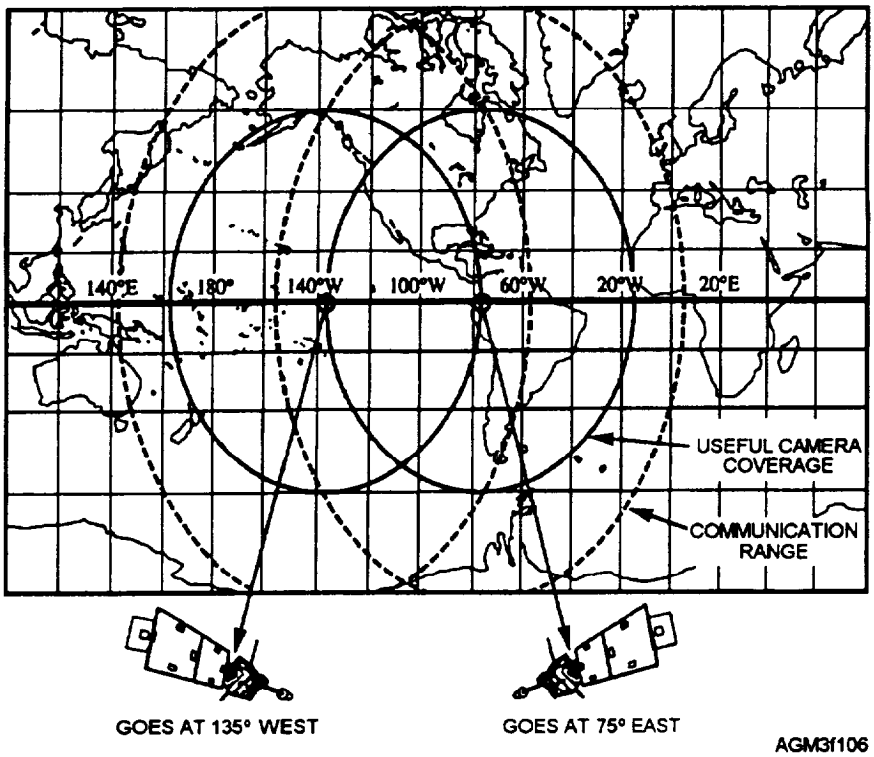


Figure 1-6.—Data coverage of GOES East and GOES West satellites.

NOAA operates two geostationary satellites known as GOES East and GOES West. The GOES East satellite (currently GOES-8), is located over 75° west longitude while GOES West (currently GOES-9) is located over 135° west longitude. Figure 1-6 shows the area of the earth covered by GOES East and GOES West.

POLAR ORBITING SATELLITES

Polar orbiting satellites closely parallel the earth's longitude lines. They pass over the vicinity of the North and South Poles with each revolution. As the earth rotates to the east beneath the satellite, each pass monitors an area to the west of the previous pass. Since

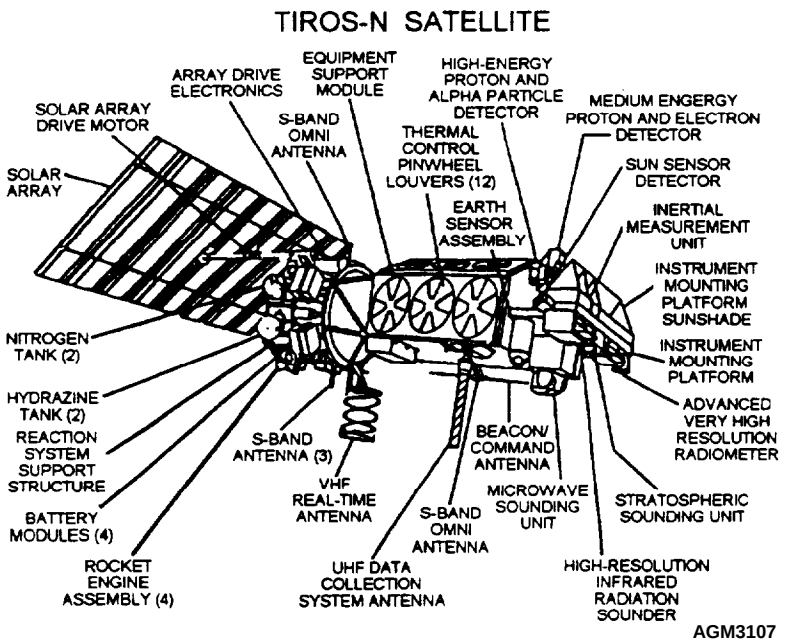


Figure 1-7.—Advanced TIROS-N satellite.

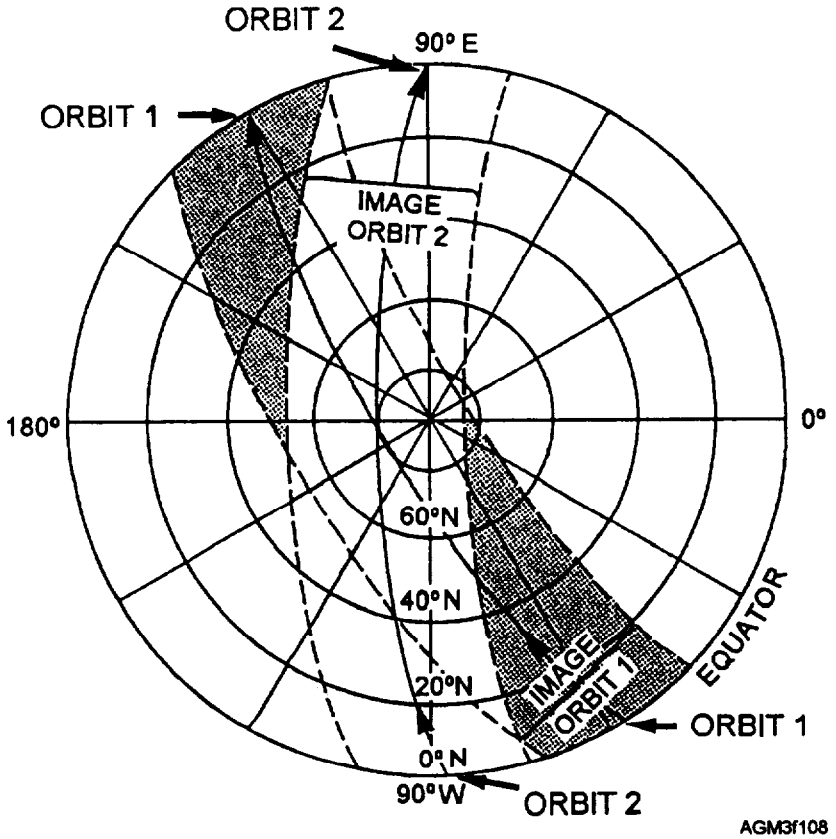


Figure 1-8.—Data coverage on successive orbits of a polar-orbiting satellite.

polar-orbiting satellites circle the earth at a much lower altitude (about 850 km), they have the advantage of photographing clouds directly beneath them at relatively high resolution. Although nearly every environmental satellite provides both infrared and visual imagery, polar-orbiting satellites are better suited to gathering imagery from the high-latitude and polar regions. They also provide imagery as they cross the equatorial regions. This makes them extremely well suited for oceanographic applications where slow changes in water temperature are adequately tracked by only two or four images a day.

The width of the usable image from a polar-orbiting satellite is a function of the satellite's altitude. The average swath width is about 2700 km (1500 nmi). Polar-orbiting environmental satellite orbits are planned so that the usable image area overlaps slightly. Figure 1-7 shows a typical TIROS-N satellite, while figure 1-8 shows the area covered by usable imagery on successive orbits of a polar-orbiting satellite.

As of this writing, NOAA 12 (TIROS-ND) and NOAA 14 (TIROS-NJ) are the two fully operational polar-orbiting satellites in the TIROS-N series. A new series of polar-orbiting satellites will be launched by the spring of 1998, and will be referred to as NOAA-POES (NOAA-Polar-orbiting Operational Environmental Satellite). Table 1-1 compares various characteristics between geostationary and polar-orbiting satellites.

Table 1-1.—Geostationary Versus Polar-orbiting Characteristics

Characteristic	Geostationary	Polar Orbiting
1. Image frequency	15 minutes	12 hours
2. Resolution at high latitudes	Poor	Good
3. Areal coverage	Full disk	2,700 km wide strip
4. Gridding	Automatic	At receiving station
5. Data acquisition system cost	Very expensive	Inexpensive
6. Average life expectancy	5-6 years	3-4 years

DMSP SATELLITES

DMSP satellites are polar-orbiting satellites managed by the Department of Defense that provide very high-resolution imagery. These satellites can provide real-time worldwide support to operating forces for both shipboard and selected shore sites. Near real-time (stored) environmental imagery can also be provided by the Fleet Numerical Meteorology and Oceanography Command (FNMOC) at Monterey, California. Because imagery from DMSP satellites is encrypted for transmission, special processing equipment is required for download.

Each direct transmission received from DMSP contains two channels, visible and infrared. The channels are transmitted so that one channel will provide "fine" data (0.56 km resolution) and the other will provide "smooth" data (2.7 km resolution). Unique sensors aboard DMSP satellites allow for the collection of visual imagery at night by using lunar illumination. The determination of channel assignment is made by the Air Force Weather Agency located at Offutt AFB, Nebraska.

DMSP satellites also have a special passive microwave sensor known as a SSM/I (Special Sensor Microwave/Imager). The SSM/I measures thermal energy emitted and reflected by the earth's surface and atmosphere by using the microwave portion of the electromagnetic spectrum. SSM/I data is particularly useful in water vapor and sea ice analysis. In addition, wind speeds over ocean areas can be estimated by evaluating the brightness temperatures of the white caps of the waves. DMSP satellites are launched as "F" series satellites (F-12, F-13, etc.).

A few satellites are equipped with a high-frequency radar device known as a *scatterometer.* A scatterometer measures reflected microwave signals from ocean waves. This data is then used to estimate low-level wind speed and direction over data sparse ocean areas. Scatterometry data is available from FNMOC.

FOREIGN SATELLITES

Several other countries also support active meteorological satellite programs. China operates a geostationary satellite called the *Fengyun.* Russia has *Meteor* polar-orbiting satellites and *GOMS* geostationary satellites in service. They also support a joint project with India that has a geostationary satellite—the *INSAT,* in place over the Indian Ocean. Japan supports a geostationary satellite called the GMS over the western Pacific Ocean. In Western Europe, several nations jointly support the European Space Agency (ESA). ESA maintains a geostationary meteorological satellite called *METEOSAT* in place over the Mediterranean region. Figure 1-9 shows the global-scale monitoring program of the World Weather Watch Global Observation System.

New satellites are routinely placed in orbit to replace older satellites as they wear out and fail. Each new satellite usually incorporates new technology and may provide slightly higher image resolution or an entirely new type of sensor. As you read this, the satellites just mentioned may be out of service and replaced by newer models.

Information concerning the operational status of all environmental satellites is available via the Internet at the *NOAASIS* world wide web site operated by NOAA/NESDIS. This site provides updated position data for geostationary satellites as well as tracking information bulletins for polar-orbiting satellites. The

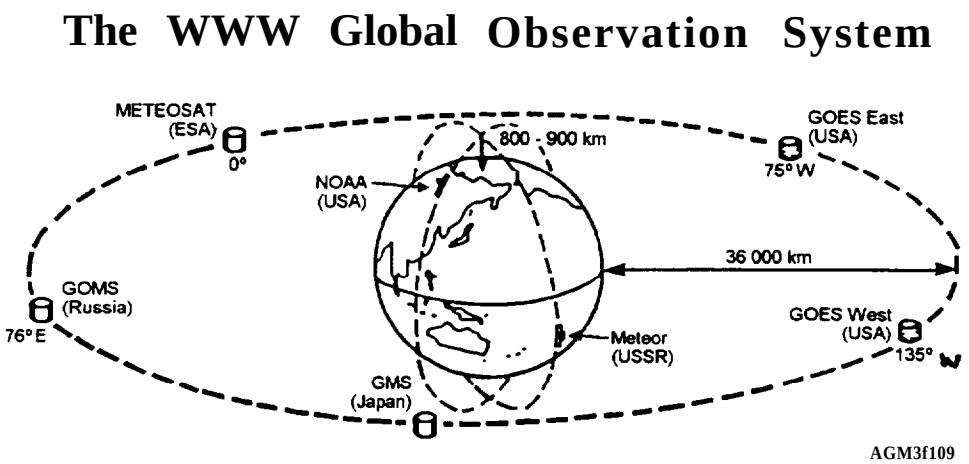


Figure 1-9.—The World Weather Watch Global Observation System.

site also contains transmission schedules and transmitting frequencies for various United States and foreign-operated satellites.

REVIEW QUESTIONS

Q7. What is the purpose of a satellite atmospheric sounder?

Q8. What is the main advantage of geostationary satellites?

Q9. Which GOES satellite provides imagery over all of South America?

Q10. What type of satellite is the NOAA 14?

Q11. What are the main advantages of polar-orbiting satellites?

Q12. What is the average swath width of a polar-orbiting satellite?

Q13. Which organization is responsible for providing near real-time DMSP environmental imagery to the fleet?

Q14. Which geostationary satellite will provide imagery for Spain and Portugal?

SATELLITE IMAGERY

LEARNING OBJECTIVES: Recognize the particular advantages of imagery from geostationary satellites and polar-orbiting satellites. Define spatial resolution, radiometer, electromagnetic wave, and albedo. Define the terms *visual, infrared, near infrared,* and *water vapor* as they relate to satellite imagery. Recognize the advantages of visual, infrared, and water vapor imagery.

The pictures or images available from environmental satellites vary, depending on the type of satellite and the type of sensor in use. Geostationary satellites continuously "look" at the same geographical area of the earth. However, the image area is centered on the satellite subpoint on the equator. At the subpoint, clouds are seen from directly overhead. Further away from the subpoint, clouds seen in the image are viewed from an angle, and feature distortion occurs. Cloud cover is often overestimated toward image edges because the sensor is actually viewing the clouds from the side. Near the horizon, the image is considered unusable due to distortion.

Polar-orbiting satellites are in much lower orbits than geostationary satellites; therefore, the satellite can only see a limited portion of the earth as the satellite sensors scan from horizon to horizon. Because of the acute view angle near the horizon, the satellite image near the horizon is usually of little value and is usually not processed or displayed by receiver station equipment.

IMAGERY RESOLUTION

Satellite sensors designed to produce pictures or images of earth, its oceans, and its atmosphere are very different from the cameras used to take a photograph. They are more like a video camera, only much more specialized. These scanning sensors are called *radiometers,* and instead of film, an electronic circuit sensitive only to a small range of electromagnetic wavelengths measures the amount of energy that is received. Satellites may can-y several different image sensors, each of which is sensitive to only a small band of energy at a specific wavelength. The radiometer used by the TIROS-N and POES series satellites is known as the Advanced Very High Resolution Radiometer (AVHRR) and contains many types of sensors.

Satellite sensors scan across the surface of the earth in consecutive *scan lines* along a path normal to the direction of travel of the satellite. As the sensor moves through a scan line, it very rapidly measures energy levels for only a very small portion of the earth at a time. Each individual energy measurement will compose a single picture element or *pixel* of the overall satellite image. The sensor then assigns an intensity level from 0 to 256 for each pixel. The size of the area (field-of-view) scanned by the sensor determines the *spatial resolution* of the overall image. Thus, the **smaller** the area scanned for each pixel, the **higher** the spatial resolution. Some sensors may scan an area as small as 0.5 km across (high resolution), while others scan areas as large as 16 km (low resolution). When composed into an image, smaller pixels allow the image to be much clearer and show greater detail. Clouds and land boundaries appear better defined. If objects are smaller than the sensor resolution, the sensor averages the brightness or temperature of the object with the background. Normally, the sensors aboard satellites are able to provide better resolution for visual imagery than for infrared imagery. DMSP satellites have very high-resolution capabilities in both visual and infrared.

TYPES OF IMAGERY

All things (with a temperature above absolute zero) emit radiation in the form of electromagnetic waves. The wavelengths emitted by each object depend primarily on the object's temperature. Higher temperatures cause electrons to vibrate faster and therefore produce shorter wavelengths. The sun emits radiation at several different wavelengths, and the range of these wavelengths is known as the *electromagnetic spectrum* (fig. 1-10, view A). Electromagnetic wavelengths in the visual and infrared region are usually measured in *micrometers.* A micrometer is equal to one-millionth of a meter and is represented by the symbol μm. Micrometers are also referred to as microns.

The sun emits a maximum amount of radiation at wavelengths near 0.5 μm. The earth, which is obviously much cooler, emits most of its radiation at longer wavelengths of between 4 and 25 μm. For this reason, the earths radiation is referred to as *long-wave radiation* and the sun's energy is referred to as *shortwave radiation.* The atmosphere is a strong absorber of radiation at certain wavelengths and is relatively transparent to others. Generally, the atmosphere is transparent to wavelengths associated with incoming solar radiation; but because of the presence of water vapor, carbon dioxide, and other elements, the atmosphere is largely opaque to the outgoing terrestrial wavelengths.

When data signals from a satellite sensor scan are compiled at the satellite receiver on earth, the pixels and scan lines form an image. The image composed of measurements of energy in the visual range forms a *visual image.* The data from sensors that measure energy in the infrared band compose an *infrared image.*

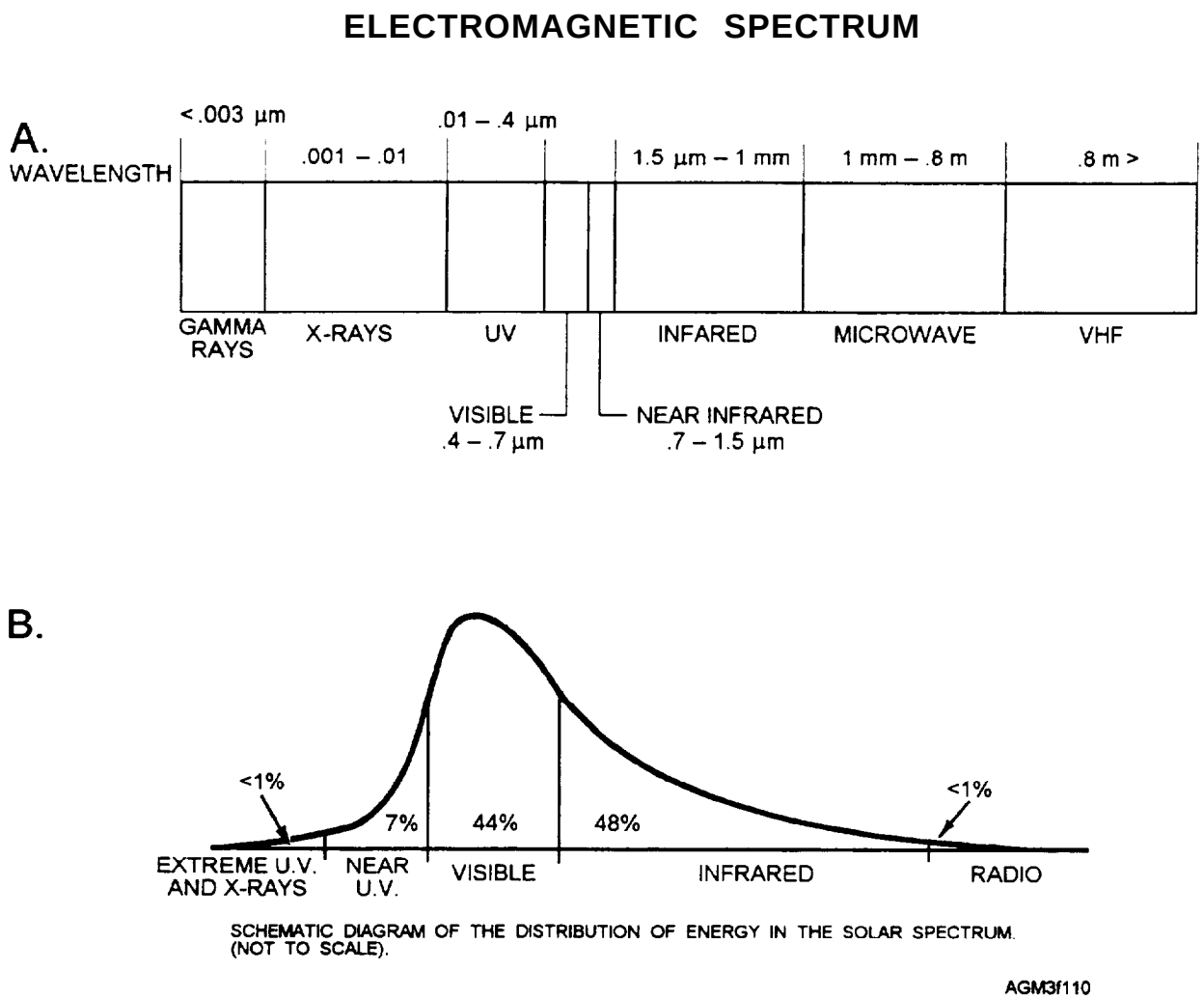


Figure 1-10.—(A) The electromagnetic spectrum, and (B) the distribution of solar energy incident to the earth.

Visual Imagery

The electromagnetic energy that your eyes can see, *visible light*, ranges from a wavelength of .7 μm for red light, through the visible spectrum (red, orange, yellow, green, blue, indigo and violet) to .4 μm for violet light. Figure 1-10, view B, shows the distribution of the various wavelengths of solar energy incident on the earth's atmosphere. About 44 percent of the sun's energy falls on the earth in the form of light. Although some light is absorbed, much of the light incident on the earth's atmosphere and surface is reflected back into space.

The reflected light from the earth is measured by a sensor aboard the satellite that is sensitive only to electromagnetic energy in the visual range. The sensor measures the energy seen in each pixel and assigns it a reading from 0 for no energy sensed to 256 for very high energy sensed. Measurements are transmitted to the earth, and the consecutive pixels and scan lines are processed to compose an image.

The more direct sunlight reaching objects, the brighter they will appear. The amount of reflectivity of an object is termed *albedo*, and is dependent on the object's surface texture and color. In visual-range images, areas of low reflected light (low albedo), such as water and forest regions, appear black. Areas of high reflected light (high albedo), such as snow, appear white (fig. 1-11). Cloud tops reflect a lot of light, so they are usually very light shades. Space surrounding earth reflects no light, so it appears black.

Visible imagery is very useful in both atmospheric and oceanographic analysis because reflectivity varies considerably among atmospheric, land, and oceanic features. An obvious disadvantage of visible imagery is that it is only available during daylight hours.

Infrared Imagery

Look again at figure 1-10, view B. You can see that most of the sun's energy that falls on the earth is in the infrared band. Most of the shorter wavelengths of infrared energy are reflected from the earth much the

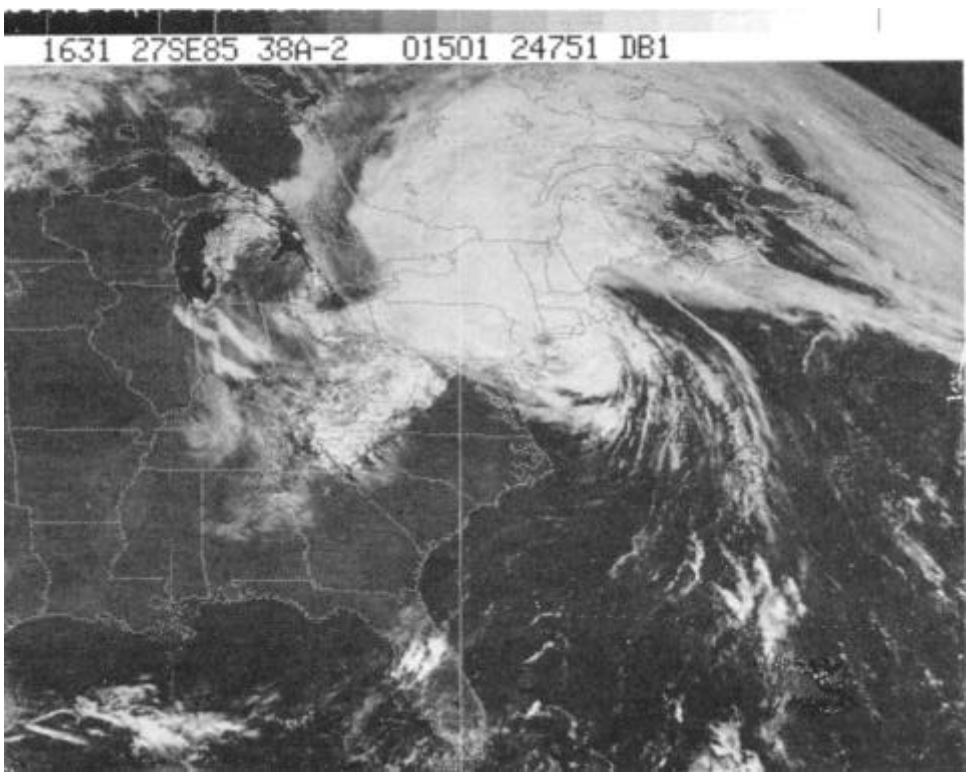


Figure 1-11.—GOES visual (VIS) image. Space and low reflective areas appear black, while high reflective areas, such as cloud tops, appear white.

same as visible light (longer wavelength infrared energy is absorbed). Satellites normally carry sensors that measure energy levels in several specific bands of infrared wavelengths, and the radiation measured is directly related to the temperature of the different radiating surfaces. Since all surfaces radiate some amount of thermal (heat) energy, a major advantage of infrared satellite imagery is that it is available even when the earth is dark. Energy levels are measured much the same way that visual-range energy is measured. The individual measurements from each pixel, when composed into an image of the earth, form an *infrared image.*

Most infrared satellite imagery is measured at wavelengths of 10.2 µm to 12.8 µm (far infrared). Some satellites are able to augment visual and far infrared imagery by also measuring near infrared (NIR) wavelengths (.74 µm to 2.0 µm). NIR imagery generally shows better land/water contrast and simplifies low-level feature identification, such as shorelines, snow/ice, and vegetation.

The satellite receiver and processor control how the composed image will look. Normally, the energy measurements for infrared image pixels are assigned g-ray shades with low-energy readings appearing white and high-energy readings appearing black. The lighter the gray shade, the colder the object seen. With IR images, space surrounding the earth is white, and warm land or water masses are dark gray or black.

Infrared imagery is an excellent tool for oceanographic analysis, such as evaluating sea surface temperatures and determining ocean front and eddy locations. It is also very helpful for identifying high clouds and upper-level wind flow, but less reliable for identifying low-level features. Look at figure 1-12. Notice how lower level clouds, very distinct in the visual image, are more difficult to determine in the

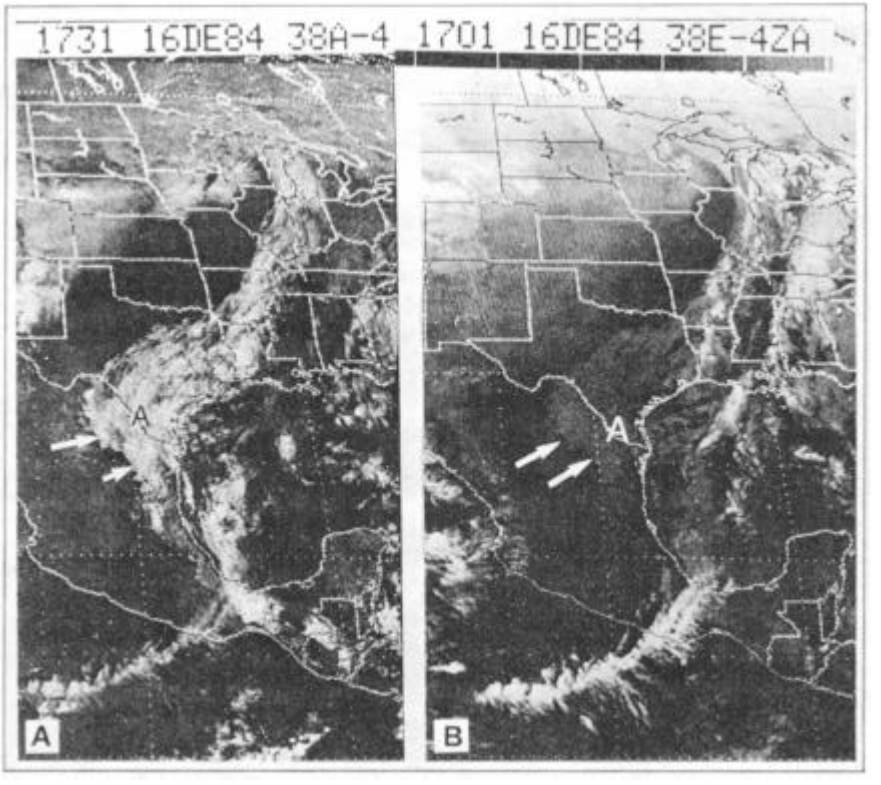


Figure 1-12.—GOES visual image on left compared to GOES infrared (IR) image on right. Space and cold cloud tops appear white and warm water and land areas appear dark gray to black in an IR image.

infrared image when surface temperatures and cloud top temperatures are relatively the same.

Water Vapor Imagery

Concentrations of water vapor in the atmosphere absorb essentially all 6.7 μm radiation coming from below. Thus, one of the infrared sensors carried aboard the GOES and the METEOSAT measures radiation at this wavelength. When the energy measurements from this type of sensor are composed into an image, the result, shown in figure 1-13, is called a water-vapor channel or *WV* image. Areas of high water-vapor content (high humidity) appear in the lighter gray shades while lower humidity areas appear darker.

The main advantage of the water vapor channel is better definition of the moisture distribution in the upper atmosphere. If moisture is present in the upper levels, we associate this with upward vertical motion. Conversely, upper-level dryness is a good indication

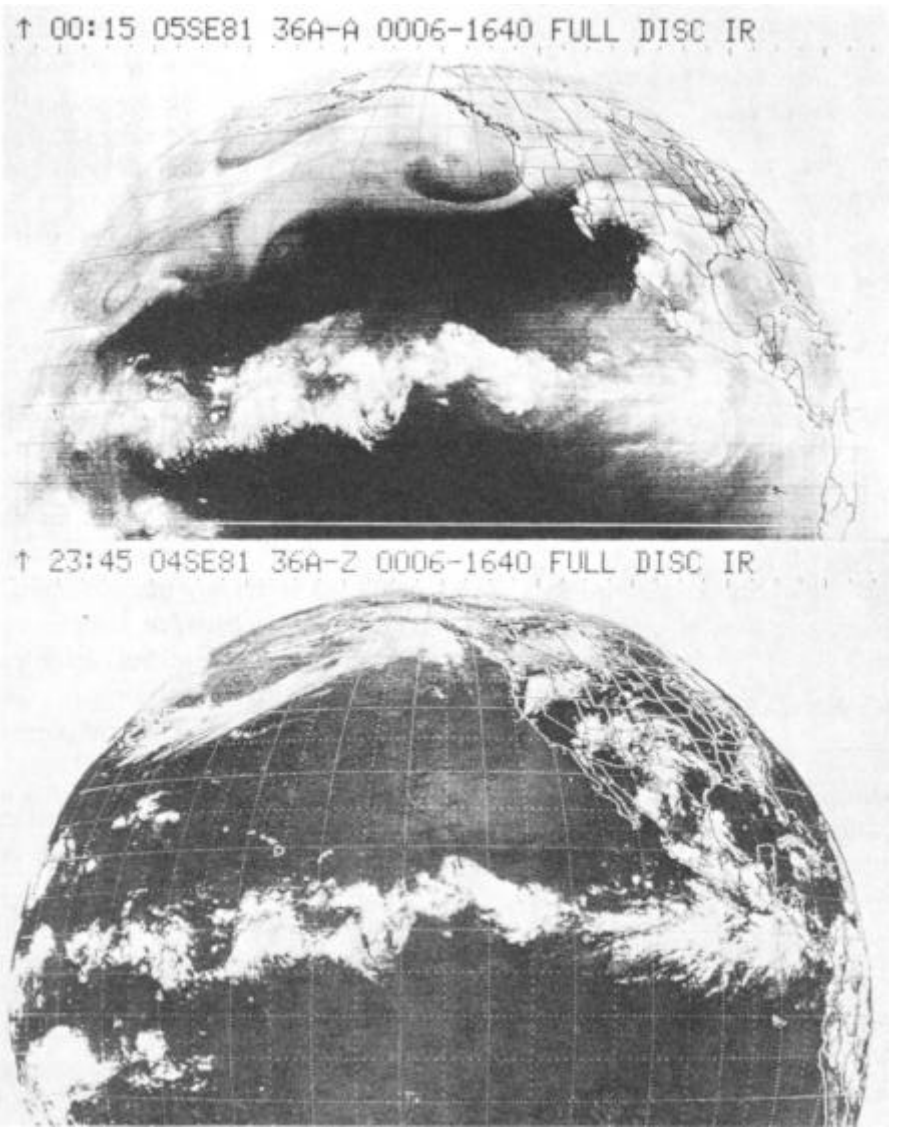


Figure 1-13.—GOES full disk (hemisphere) infrared water-vapor (WV) channel image (top) and full disk visual (VIS) image (bottom) at the same time. The WV image shows a better depiction of the extent of the system than the VIS image.

of downward vertical motion. Water vapor imagery can detect these motions without clouds present. Circulation patterns in the upper atmosphere, including the jet stream, are easily identified using WV imagery.

REVIEW QUESTIONS

Q15. What is the image-scanning sensor of a satellite called?

Q16. Which sensor would provide higher resolution data, one with a spatial resolution of 1 kilometer or one with a spatial resolution of 4 kilometers?

Q17. *Consider two objects, one cold the other hot. Which object is emitting electromagnetic energy at relatively longer wavelengths?*

Q18. *The majority of the radiation emitted by the earth is known by what term?*

Q19. *In the visible spectrum, what color has the longest wavelength?*

Q20. *Of the following objects, sand or grass, which one would have a higher albedo?*

Q21. *What are the major advantages of infrared imagery?*

Q22. *How do relatively cold objects appear on IR imagery?*

Q23. *How do high humidity areas appear on water vapor images?*

Q24. *What are the advantages of water vapor imagery?*

IMAGERY ENHANCEMENT

LEARNING OBJECTIVES: Identify various types of user-defined and predefined satellite enhancement curves. Identify information contained in the GOES legend and temperature scale.

Most satellite data processors have the capability to assign colors or various gray shades to specific JR imagery energy readings. When an image is produced by using either color or an alternating gray shade rather than the straight black-to-white or white-to-black shading, the color or gray shade assignment is called an *enhancement.* An enhanced satellite image allows the user to see specific details of an image with better definition. Infrared imagery is often enhanced to better define a small range of critical temperatures.

TYPES OF ENHANCEMENT CURVES

Unenhanced imagery displays a linear transition of gray shades from black (warm) to white (cold). It is a steady increase in brightness that produces little contrast. Enhanced imagery displays a transition of mostly non-linear gray shades. The result is an improved contrast of various key temperatures that makes specific temperature assessment much easier. There are two methods of enhancing satellite imagery: brilliance inversions and thresholding (curves). Brilliance inversion enhancements use a range of gray shades (or color) to identify a range of specific temperatures. With threshold enhancements, a single gray shade is used to identify a whole range of temperatures. In other words, all the temperatures in a particular range have the same gray contour. Figure 1-14 shows enhanced infrared images.

User-Defined Enhancement Curves

When possible, enhancement curves should be locally developed and evaluated. Most satellite receiving equipment used by the Navy, such as the AN/SMQ-11, allow for the creation of custom designed enhancement curves. Keep in mind that when you are developing enhancement curves, you should limit the number of features to be enhanced. You must allow for enough detail as possible without making the display too confusing. There are always compromises between simple enhancement curves, which sacrifice detail but can quickly be interpreted in an operational environment, and complex curves, which maximize information content but require more time to interpret.

Figure 1-15 is a graphic illustration of a basic enhancement curve table. Count values as input would be plotted on the horizontal axis, and modified count values for the final display would be plotted on the vertical axis. These count values range from 0 to 255, where 0 appears as black and 255 appears as white. Values in between produce varying shades of gray. By adding, deleting, and positioning points within the graph, an input color or gray shade is mapped to an output color or gray shade. As points of reference, six count values on the horizontal axis correspond to the six sets of temperatures at the bottom of the graph. Count values on the vertical axis result in the gray shade range as referenced at the right of the graph. The

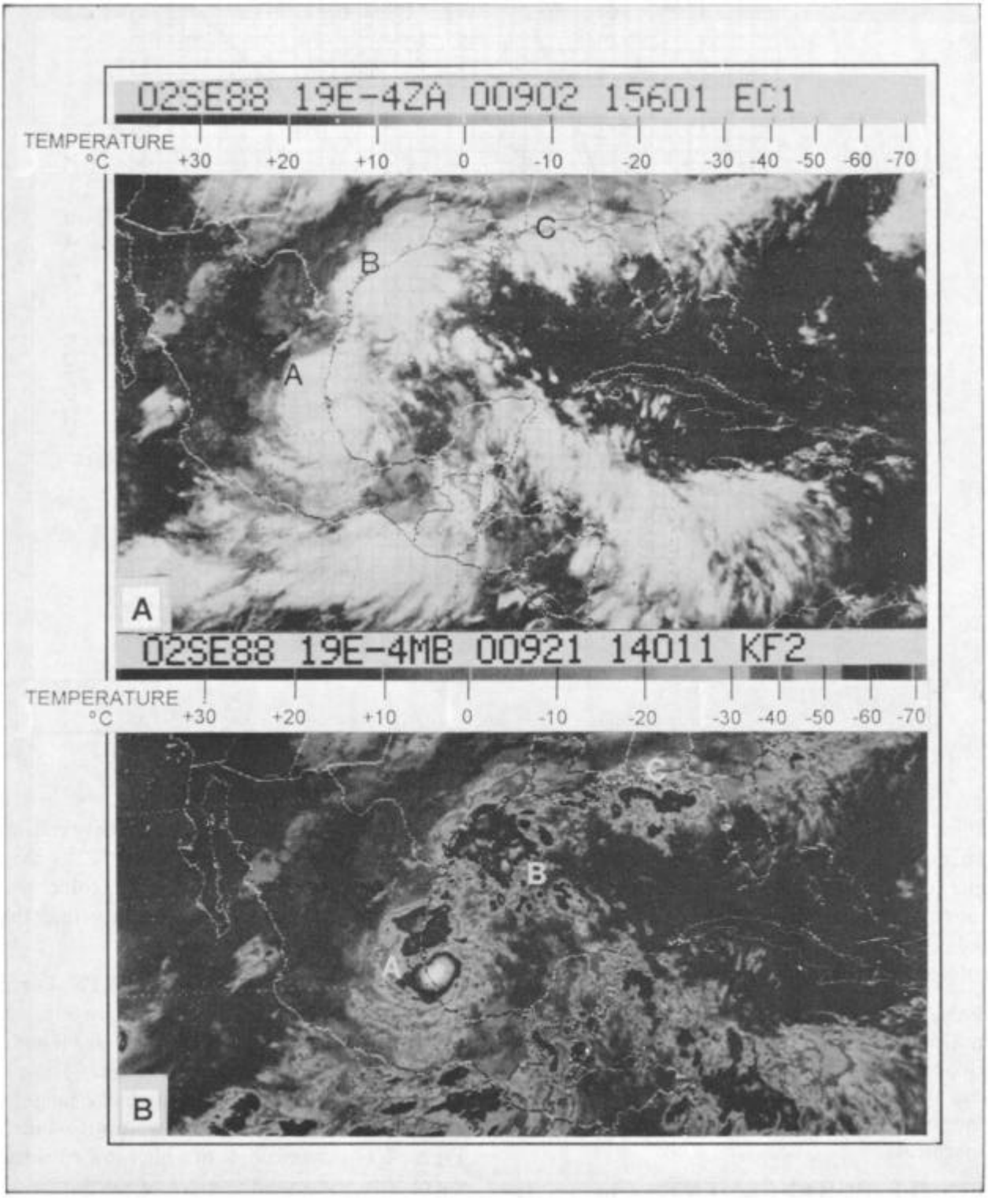


Figure 1-14.—Processed GOES infrared images with temperatures added to gray-shade scale. (A) A predefined "ZA" enhancement (straight black to white shading) and (B) a predefined "MB" enhancement used to better define cloud-top temperatures (cloud height) in thunderstorms at points A, B, and C.

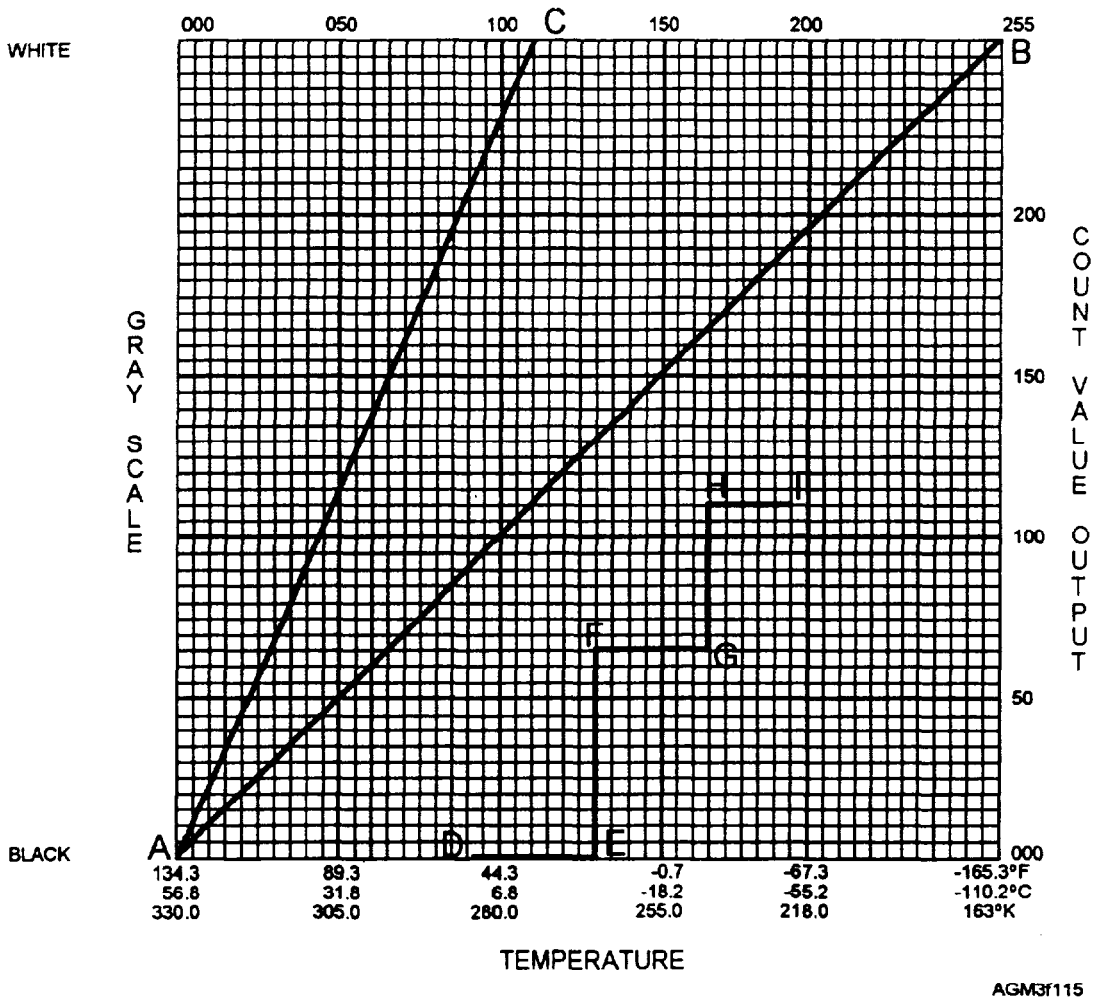


Figure 1-15.—Illustration of a basic enhancement curve table.

solid line (AB) represents a case of no enhancement. As an example, if you acquired an image and the warmer (darker) end of the spectrum required greater definition, the data could be modified as illustrated by the segment (AC). In this case, all the gray shades from +56.0°C to 5.8°C would be displayed.

Enhancement curves for high-resolution imagery from DMSP and NOAA satellites are usually developed based upon three basic configurations, depending on desired results. They are the single enhancement, the high-low enhancement, and the split enhancement.

SINGLE ENHANCEMENT.—The single enhancement curve is defined over a complete count value range, but for either a default or specified temperature range. This curve will give you all gray shades across your defined temperature range. For example, if you were interested in only low clouds or sea surface temperatures, you might only enhance the image in a range from +20°C to -10°C, as shown in figure 1-16. Any areas on the image colder than the lower limit will appear white. Areas warmer than the upper limit will appear black.

HIGH-LOW ENHANCEMENT.—For high-low enhancement curves, two ranges are selected. For each of these, a unique part of the gray-shade and count value scale is applied to each range. Thus, warm temperatures may be in the gray-black range, while cold temperatures may be in the white off-white range. Figure 1-17 is an example of a high-low enhancement curve with temperature ranges of +30°C to +05°, and -20°C to -40°C. Areas colder than the lowest minimum temperature will appear white. Areas warmer than the highest maximum temperature will appear black. Areas which are temperatures between the upper and lower ranges will appear black.

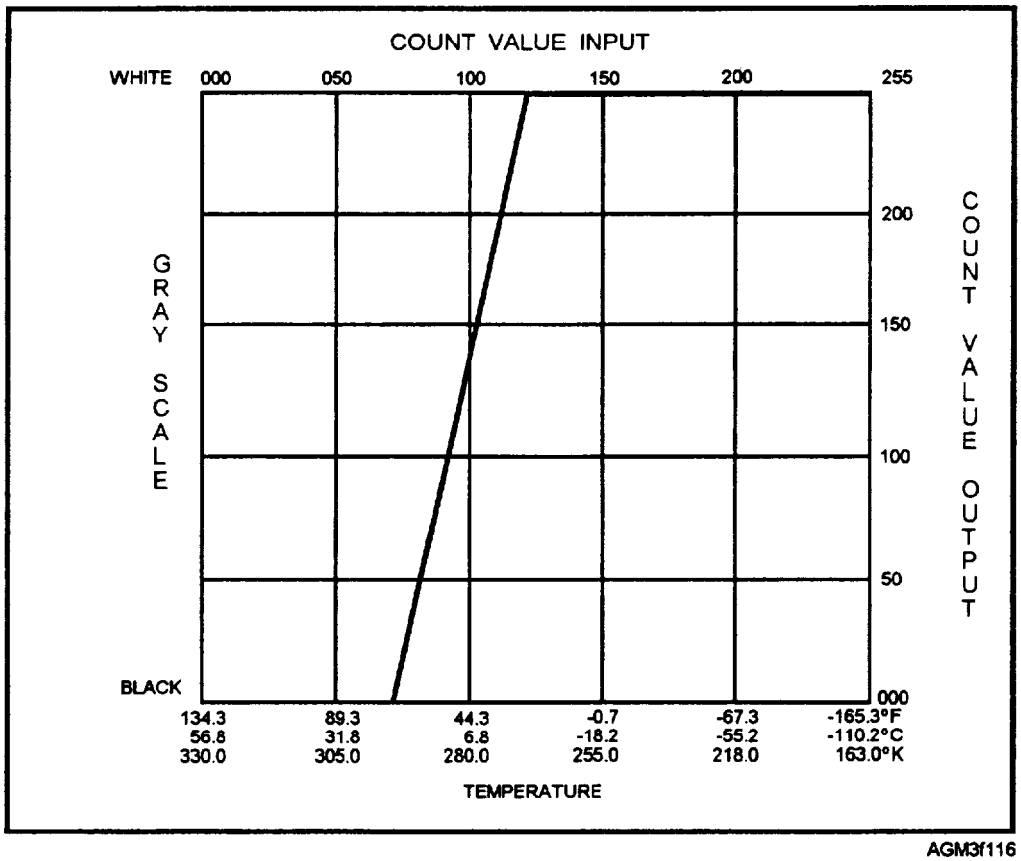


Figure 1-16.—Single enhancement curve.

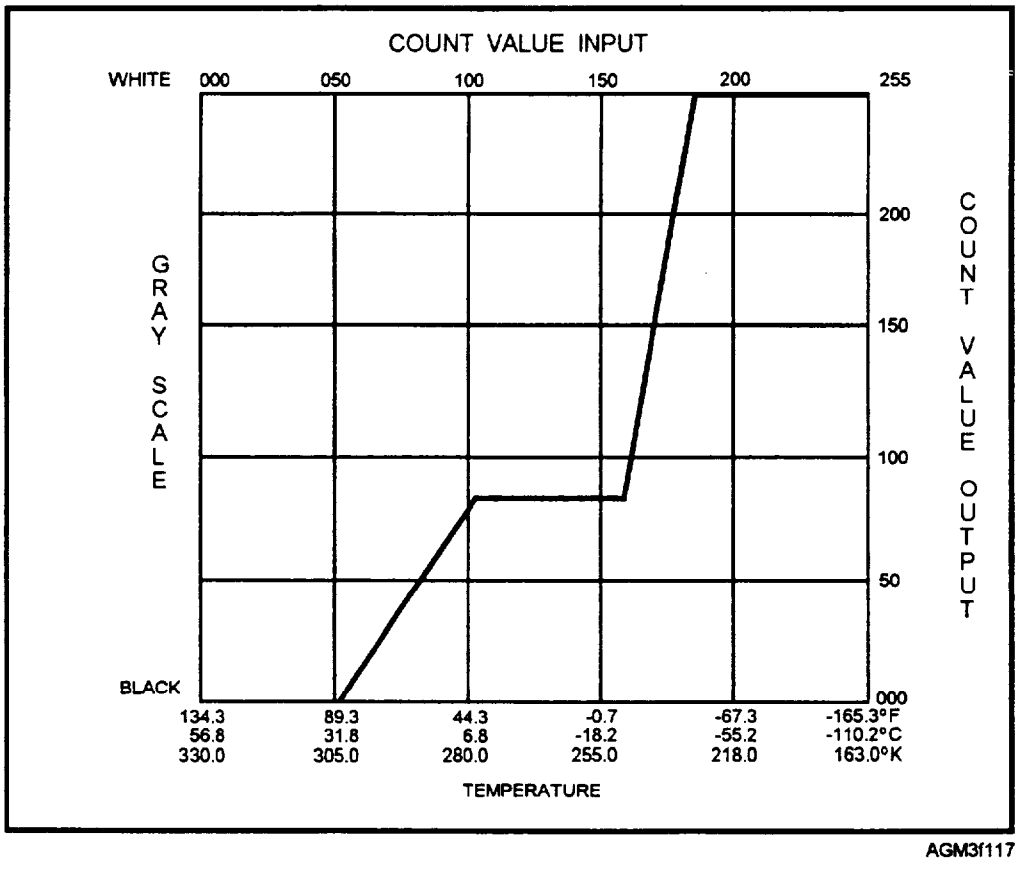


Figure 1-17.—High-low enhancement curve.

SPLIT ENHANCEMENT.—For split enhancements, two ranges are also selected. For each, the complete gray-shade and count value scale applies. This means that the complete gray shade scale is applied **twice** over the **image,** except for temperatures lying between the two defined ranges. Figure 1-18 displays a split enhancement curve for temperatures of +30°C to 0°C and -10°C to -30°C. Areas colder than the lower minimum temperature will appear white. Areas warmer than the higher maximum temperature will appear black. Areas which are temperatures between the upper and lower ranges will appear gray.

Predefined Enhancement Curves

Besides locally developed enhancement curves, there are several predefined enhancement curves available for GOES imagery that have been tested and evaluated over many years. Each of these enhancements was developed for a specific application. One of the most common is the MB Curve. This is a very good, all-purpose curve, but was specifically designed for summertime convective activity. The MB curve has very distinct contours (thresholding) around specific temperatures, and is especially helpful in picking out thunderstorms. Figure 1-19 shows the configuration of the MB curve. The *GOES* User's *Guide* contains detailed information on various predefined enhancement curves.

Visible imagery can also be enhanced by adjusting brightness values vice temperature values as with IR imagery. Enhanced visible imagery is especially useful in cases of fog and thick stratus.

GOES LEGEND INFORMATION

Much information about a particular GOES satellite image is available from the GOES legend that appears at the top of each image received over the GOES Telecommunications Access Program (GOES-TAP). An example of a GOES legend is shown at the

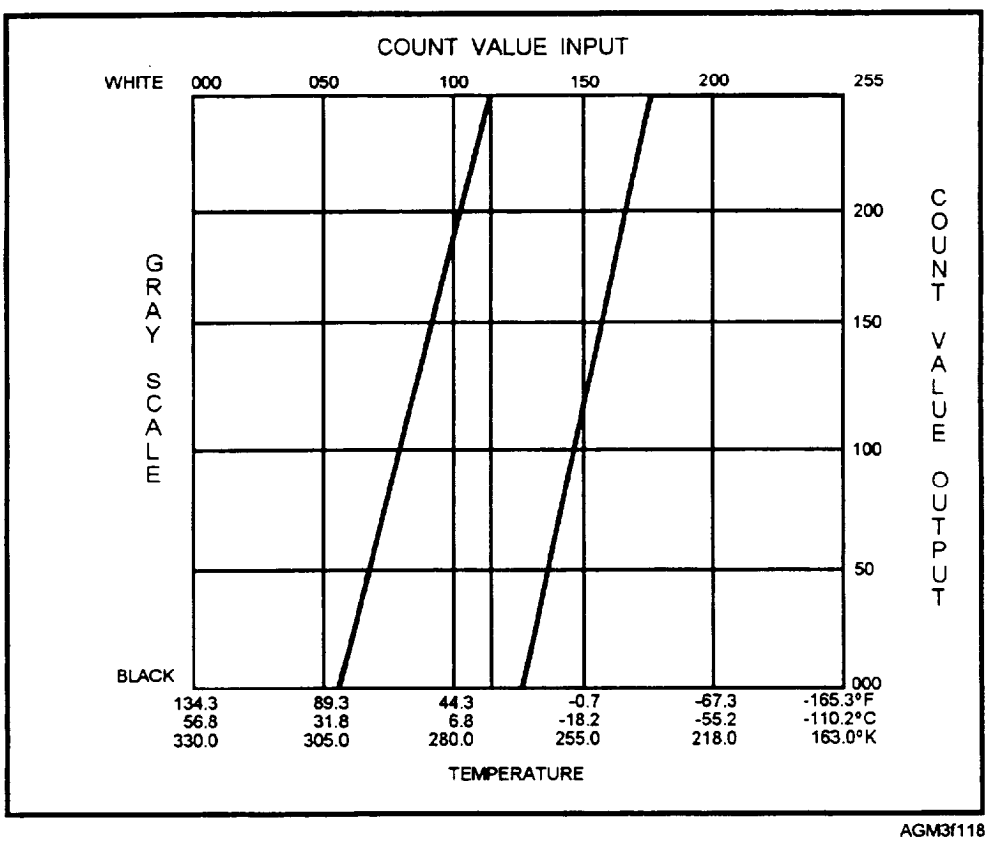
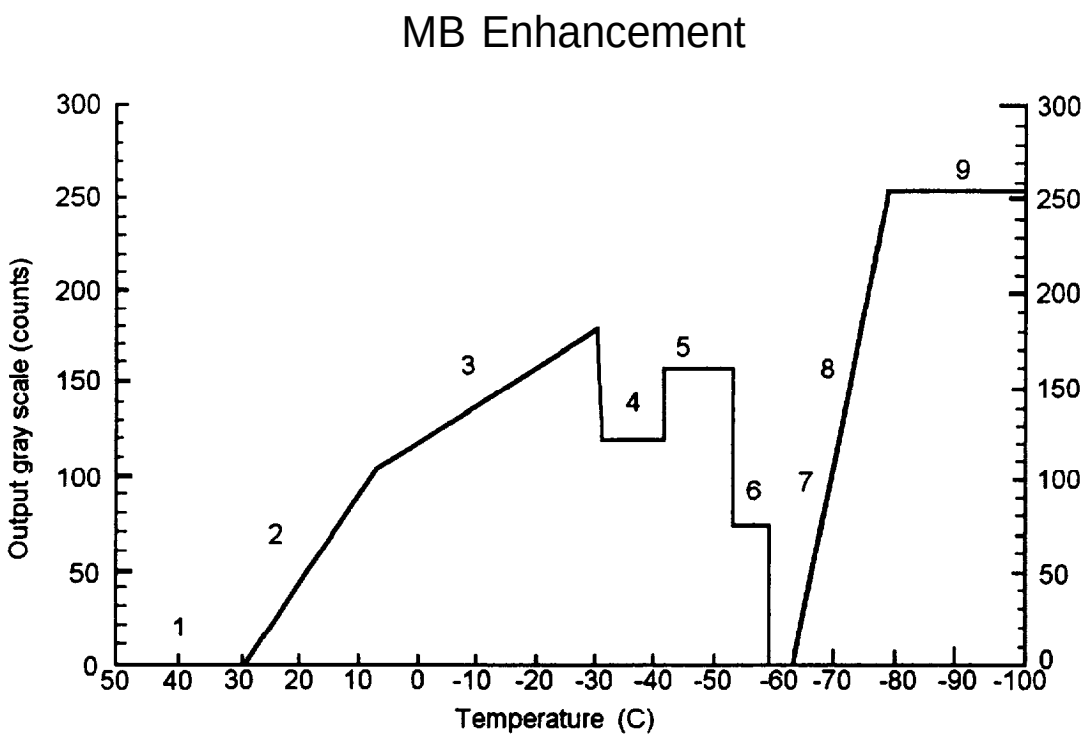


Figure 1-18.—Split enhancement curve.



Segment Number	Output count	Temperature Range (°C)	Comments
1	0 - 0	56.8 to 29.3	Little or no information
2	0 - 100	29.2 to 6.8	Surface features/warm clouds
3	101 - 176	6.7 to -31.2	Middle level clouds
4	117 - 117	-31.6 to -42.3	Cirrus/thunderstorms (Med gray)
5	155 - 155	-42.5 to -53.3	" " " (Light gray)
6	70 - 70	-53.6 to -59.4	" " " (Dark gray)
7	0 - 0	-59.7 to -63.1	" " " (Black)
8	0 - 255	-63.5 to -80.5	" " " (Repeat gray)
9	255 - 255	-81.1 to -110.1	" " " (White)

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Figure 1-19.—The GOES MB enhancement curve.

top of figure 1-20. Column 1 is the Universal Coordinated Time (UTC) and column 2 is the date of the image. The first number in column 3 indicates line stretcher/data buffer identification data and the first letter is the satellite identification indicator (I=GOES 8, J=GOES 9). The second letter in column 3 is the image type, which will be either "F" for full disk IR, "E" for the equivalent IR sector, or "A", "B", "C", "D" for the visible sectors. The next number in column 3 is the resolution in kilometers, and the last two letters in column 3 indicate the type of enhancement curve (IR imagery only). Columns 4 and 5 are for use by satellite specialists.

Column 6 of the GOES legend indicates the sector identification of the image. The term sector refers to the segments of a GOES image that are expanded or contracted to the desired geographic region of a particular GOES-TAP distribution site. The first letter indicates the satellite field distribution site for which

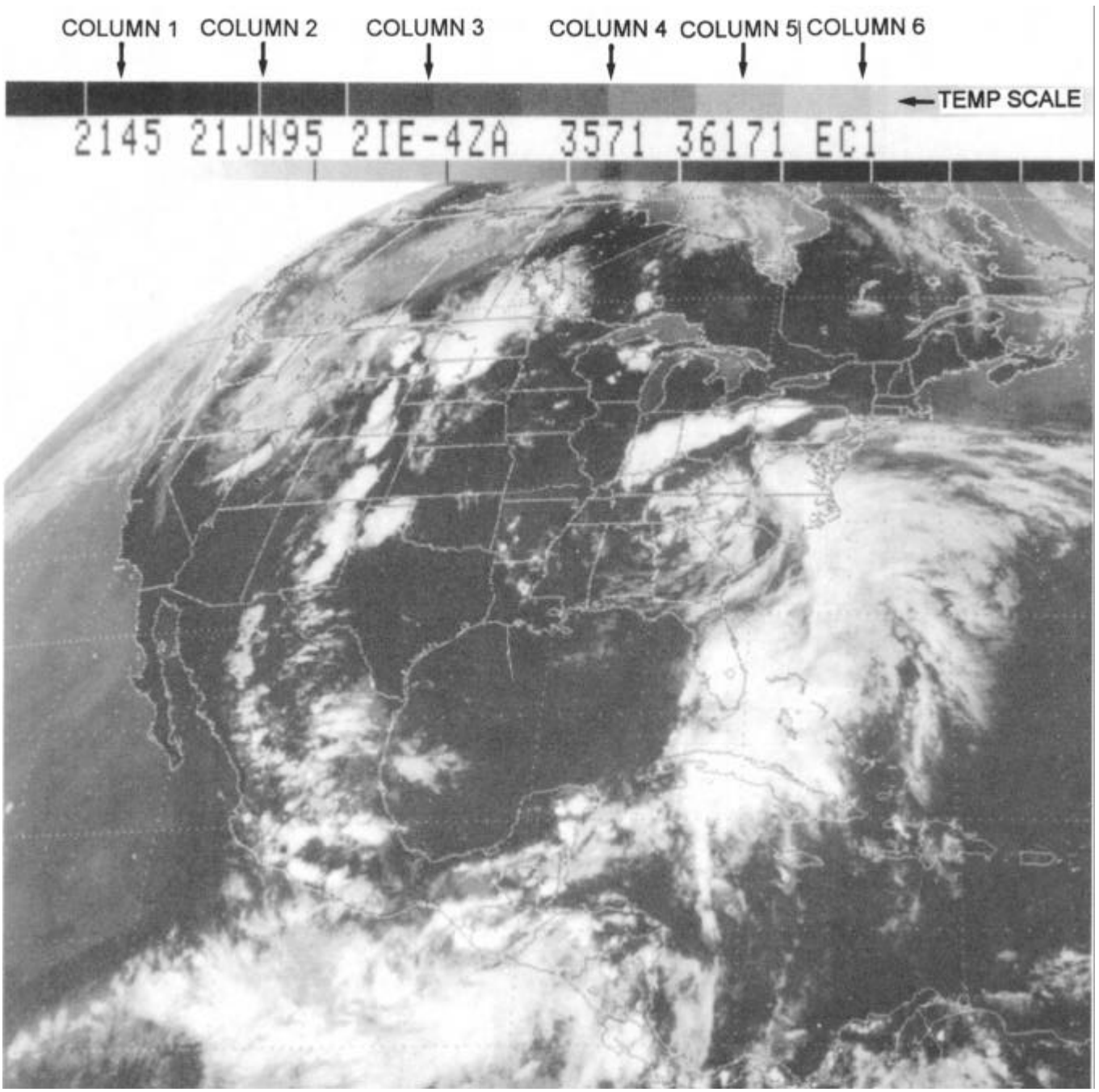


Figure 1-20.—A GOES 8 EC1 infrared sector taken at 2145 UTC, June 21,1995. The GOES legend is at the top of the image.

the sector was generated, such as "D" for Washington, D.C, or "S" for San Francisco. The next letter indicates the sector resolution in kilometers, that is A= 1 km, B = 2 km, C = 4 km, and D = 8 km (IR only). The last digit indicates the identification number of the specific sector.

GOES TEMPERATURE SCALE

The temperature scale appears only on IR and WV imagery, and it appears below the legend. The temperature scale is divided into 10°C increments with a range from +50°C to -100°C. It has 15 temperature blocks separated by white or black vertical lines. The temperature scale is very useful in cloud and non-cloud identification.

REVIEW QUESTIONS

Q25. What is the purpose of enhancing satellite imagery?

Q26. What is a major disadvantage of providing too much definition to user-defined enhancement curves?

Q27. Which type of user-defined enhancement curve applies two complete gray-shade and count value scales for two separate temperature ranges?

Q28. What is indicated in column 6 of the GOES legend?

Q29. The GOES temperature scale is normally divided into segments of how many degrees?

METHODS OF ACQUIRING IMAGERY

LEARNING OBJECTIVE: Identify the various methods used to acquire environmental satellite imagery.

There are several ways to receive satellite imagery: weather facsimile broadcast; Navy Oceanographic Data Distribution System (NODDS); GOES Telecommunications Access Program (GOES-TAP); satellite direct-readout service; weather facsimile service (WEFAX); the Internet; and AUTODIN message.

WEATHER FACSIMILE BROADCAST

Some ships may receive a low quality satellite image as part of the U.S. Coast Guard facsimile broadcast. Transmitted via high-frequency (HF) radio, this broadcast transmits National Weather Service charts and satellite imagery on a fixed schedule. Schedules and frequencies for facsimile broadcasts originating from CONUS stations (San Francisco, New Orleans, Boston, and Kodiak) are available over the Internet. Several other countries, such as Japan and India, also transmit weather charts and satellite imagery via HF. A listing of all maritime weather broadcast frequencies is available in the latest edition of *Worldwide Marine Radiofacsimile Broadcast Schedules* published by NOAA.

NAVY OCEANOGRAPHIC DATA DISTRIBUTION SYSTEM

The Navy Oceanographic Data Distribution System (NODDS) is a dial-up data service available from FNMOC. Although originally designed to transmit graphical data fields for portable computer systems, selected satellite imagery is now available within a few hours of sensing. Authorized users may access the system from anywhere in the world via computer modem through the U.S. Govemment-owned Internet routing networks or via direct long-distance telephone connection on commercial or Defense Switched Network (DSN) lines. Information on NODDS satellite imagery is available in the *Navy Oceanographic Data Distribution System Products Manual.*

All of the satellite data available on NODDS is from DMSP satellites. The pictures that actually appear on your computer monitor may not be quite as clear as imagery from other sources. The imagery is considered *near real-time* in that it is available to the user usually within a few hours of sensing. The DMSP satellites collect imagery, store the information as digital data aboard the satellite, and then dump the imagery data on command as it comes within range of a receiver site capable of copying high-resolution imagery. DMSP imagery for specific, high-interest areas around the world may be requested from FNMOC after some coordination.

GOES TELECOMMUNICATIONS ACCESS PROGRAM (GOES-TAP)

Ashore, Navy and Marine Corps weather stations receive satellite imagery primarily from the GOES-TAP service. The GOES-TAP service is operated by NESDIS, and satellite images are provided via dedicated telephone circuits. The circuits are leased from commercial telephone companies and are maintained by the telephone companies that own them. Routine satellite images are transmitted at 15-minute intervals. The imagery is normally displayed on a

computer monitor that has control access to the various channels of the GOES-TAP system.

GOES-TAP users may be connected to one of several satellite field distribution facilities or be connected to another user.

When connected to a distribution hub, the user may select several different channels of imagery signals. There are several hubs located at various National Weather Service (NWS) forecasts offices, such San Francisco, Miami, and Kansas City, to name a few.

If the user is not connected directly to a hub, but connected to another user, this arrangement is appropriately called a slave connection. The secondary user has no direct choice of incoming imagery signal and only receives the data on the channel selected by the primary user. Several Navy and Marine Corps weather stations are connected as slaves. Slaved GOES-TAP users must coordinate with the primary user if a different channel of imagery is desired.

Each channel of GOES-TAP is a separate broadcast of imagery. One channel, for example, may contain only alternating visual and infrared GOES satellite images of the full disk (hemisphere) of the earth. Another channel may contain visual and infrared GOES images of only the southeastern United States. A third channel may contain imagery from the European METEOSAT. Yet another channel may contain high-resolution picture transmission (HRPT) imagery from a NOAA satellite. Enhanced infrared imagery from GOES is also routinely available via GOES-TAP.

Most GOES-TAP data is processed and analyzed by using a desktop computer with a color video monitor. The monitor is used to display both the imagery and the control menus. Initial issue equipment was the GOES-TAP Imaging System (GTIS), which used a Unisys 80386 desktop computer. Most of these systems have been replaced by the Meteorology and Oceanography (METOC) Integrated Data Display System (MIDDS). A laser printer may be connected to either system to provide hard copy prints of the imagery. Although hard copies of selected images may be made, hard copy quality is a function of the printer or imagery connected to the system. Similar equipment called the Naval Satellite Display System-Enhanced (or NSDS-E) is used at most NAVMETOCCOM centers. This system has the additional capability of copying NOAA polar-orbiter and DMSP imagery. Further changes to GOES-TAP processing equipment are very likely in the future.

Almost all satellite imagery processors have looper capability. The primary application of any looper system is to store and display a series of geostationary satellite images of the same area in a sequence that shows the movement of clouds and weather systems. Individual satellite images may also be displayed and studied. The various other display options, such as map overlay and enhancement, are menu-driven for both the GTIS and the MIDDS as is the channel selection. Instructions for using GTIS are contained in the User's Manual provided with each installation.

The MIDDS has a colorized custom enhancement function and a few systems have the additional capability of obtaining satellite images via WEFAX broadcast, HF radio, or Automatic Picture Transmission (APT) receiver. Instructions for obtaining satellite information via MIDDS is contained in the *Meteorology and Oceanography (METOC) Integrated Data Display System (MIDDS) User's Guide.*

DIRECT-READOUT SERVICE

Direct-readout service is an image-data transmission designed to be received by user-operated satellite receiver stations, such as the AN/SMQ-11 satellite terminal and the Interim Mobile Oceanography Support System (IMOSS) satellite module. The raw satellite signals are converted to an image by the receiver station. Direct-readout service is available from all polar-orbiting meteorological satellites. This service is generally not available from geostationary satellites, although a few weather activities have acquired geostationary direct-readout systems from commercial contractors.

One type of direct-readout service that is provided by the NOAA satellites is the *Automatic Picture Transmission* (APT) service. APT service provides a continuous transmission of both visual and infrared satellite imagery. The NOAA satellites transmit a pair of images, one visual and one infrared, over sunlight portions of the earth, and two different infrared channels over the dark side of the earth. The scan rate is 120 lines per minute at 4-kilometer resolution. The amount of data received by a station depends on the location of the satellite subpoint; the further the subpoint falls from the station, the smaller the area of coverage becomes.

The received APT images are *ungridded*—no latitude/longitude lines nor land/water or geographical boundaries are added to the image (fig. 1-21). APT service is also available from foreign polar-orbiting

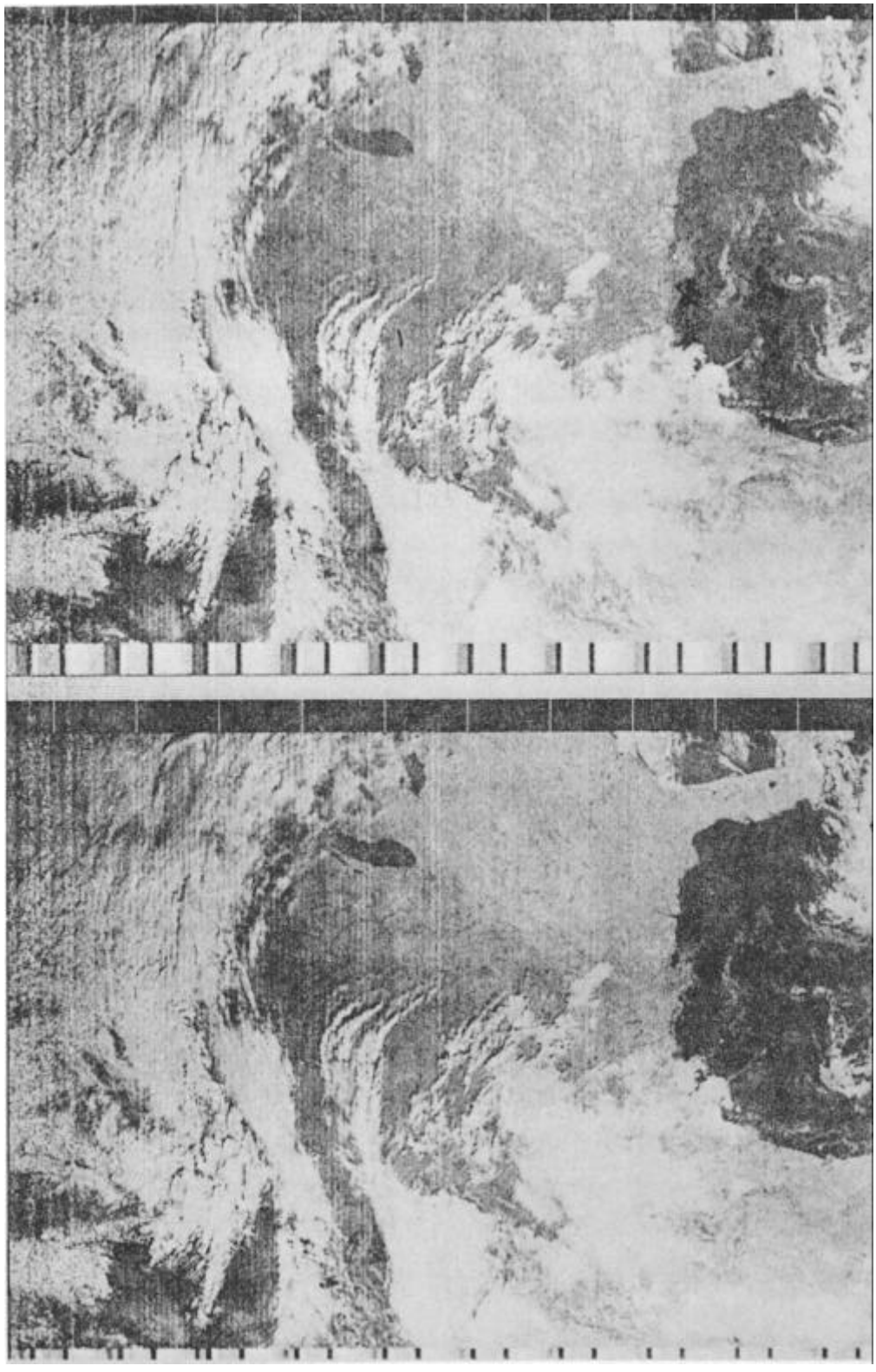


Figure 1-21.—Typical APT visual and infrared image pair from a NOAA satellite.

satellites and varies from relatively low resolution to high resolution.

APT direct-readout imagery is normally transmitted in the 136-MHz to 139-MHz band. The data signals are transmitted from the satellite to earth within seconds of being scanned by the satellite sensors. This is sometimes called *real-time* imagery; the image is available as the satellite scans the earth. APT service is designed to be received by anyone with a standard, relatively low-cost satellite receiver. Signals from DMSP satellites also provide APT. However, the signals are encrypted. Additional information on APT direct-readout services may be found in the *NOAA KLM User's Guide.*

The IMOSS satellite module can receive, process, display, grid, and enhance APT direct-readout service from nearly all polar-orbiting environmental satellites. It is not equipped to decrypt the imagery signal from the DMSP satellites. The AN/SMQ-11 is capable of copying both APT data as well as DMSP encrypted signals.

A second type of direct-readout service available from both the NOAA and DMSP satellites is the *High-Resolution Picture Transmission (HRPT)* service. This is data scanned at a rate of 360 lines per minute to provide 1.1-kilometer resolution (fig. 1-22). High-resolution imagery can be, and usually is, transmitted from satellites as a continuous broadcast. HRPT

Figure 1-22.—HRPT imagery.

imagery, like the APT direct-broadcast imagery, is received unprocessed and ungridded. Many user-operated satellite receiver systems are unable to receive and process I-IRPT imagery. The IMOSS satellite module cannot receive or process HRPT, while the AN/SMQ-11 is able to receive and process the signal.

High-resolution imagery may also be stored aboard the satellite, downloaded to a Command Data Acquisition (CDA) station on command, and sent to NESDIS in Suitland, Maryland. NESDIS processes the imagery, adds gridding, and forwards the processed signal to other imagery services. NESDIS operates two CDA stations for both the NOAA and GOES satellites: Wallops Island, Virginia, and Fairbanks, Alaska. The Department of Defense operates its own CDA stations for the DMSP satellites.

WEFAX SERVICE

Another method for receiving satellite imagery at your ship or station is to copy a WEFAX (weather facsimile) broadcast from a geostationary satellite. WEFAX is the *retransmission* of low-resolution infrared and visible satellite imagery from U.S. GOES satellites to any receiver capable of copying the signal. WEFAX transmissions are also available via METEOSAT, GMS, and other foreign satellites.

The U.S. GOES WEFAX service provides visual and infrared sectors as well as full disk imagery. The service also includes selected meteorological and oceanographic charts, TBUS bulletins, and operational messages. You can check the NOAASIS web site for information on active WEFAX broadcasts, broadcast content, and frequencies. Information concerning GOES schedules is also available via the Internet. Detailed information on WEFAX services is provided in the *WEFAX User's Guide* issued by NOAA/NESDIS.

Each GOES satellite provides high-resolution imagery that is transmitted on a high-frequency signal to the CDAs and processed at NESDIS. NEDSIS processes the signal to add gridding (latitude/longitude), geographical boundaries, borders for land and water masses, and enhancement. The CDAs then retransmit the processed signal back to the satellite for WEFAX transmission. In turn, the satellite retransmits the WEFAX signal back to earth on a lower frequency signal for reception by user-operated satellite receivers. The service is generally provided at frequencies near 1691 MHz.

The WEFAX signal is much weaker than the APT or HRPT signal from polar-orbiting satellites. Normally, a directional antenna with antenna polarity control circuits is necessary to copy the WEFAX signal. The AN/SMQ-11 is fully capable of capturing the WEFAX signal. The IMOSS satellite module can also receive and process the WEFAX signal by using a special directional antenna specifically designed to copy the broadcast.

Directional antennas should be aimed at the broadcasting geostationary satellite for the best WEFAX reception. Instructions for aiming the IMOSS WEFAX antenna are available in the *Interim Mobile Oceanography Support System (IMOSS) User's Guide.* Appendix C of the guide contains diagrams for calculating elevation and azimuth angles for different geostationary satellites.

Be aware that although international agreements call for five operational geostationary satellites, problems occasionally arise that require satellites to be moved temporarily to slightly different locations. WEFAX may also be broadcast from older geostationary satellites that have been moved out of the primary position. Figure 1-23 is a diagram frequently used to calculate the azimuth (degrees true) and elevation angles needed to find any geostationary satellite located over the equator.

To use the diagram, the user subtracts the longitude of the receiver location (site longitude) from the longitude of the satellite to find delta (Δ), (ignore the sign). Using the value of Δ (scale on the left side of the diagram with 80 degrees at the bottom and 3 degrees at the top), follow parallel to the drawn lines sloping downward toward the right. Using the receiver station latitude (site latitude) on the Γ scale (right side of the diagram), follow parallel to the lines sloping downward toward the left to the intersection of the Δ value. The antenna elevation angle (look elevation) is found by drawing a horizontal line toward the left to the *look elevation* scale. The antenna azimuth is found by drawing a vertical line downward to the *look azimuth* scale. The four azimuth scales are used as follows:

- SW - When receiver is **south** of the equator and **west** of the satellite's position
- SE - When the receiver is **south** of the equator and **east** of the satellite's position
- NE - When the receiver is **north** of the equator and **east** of the satellite's position

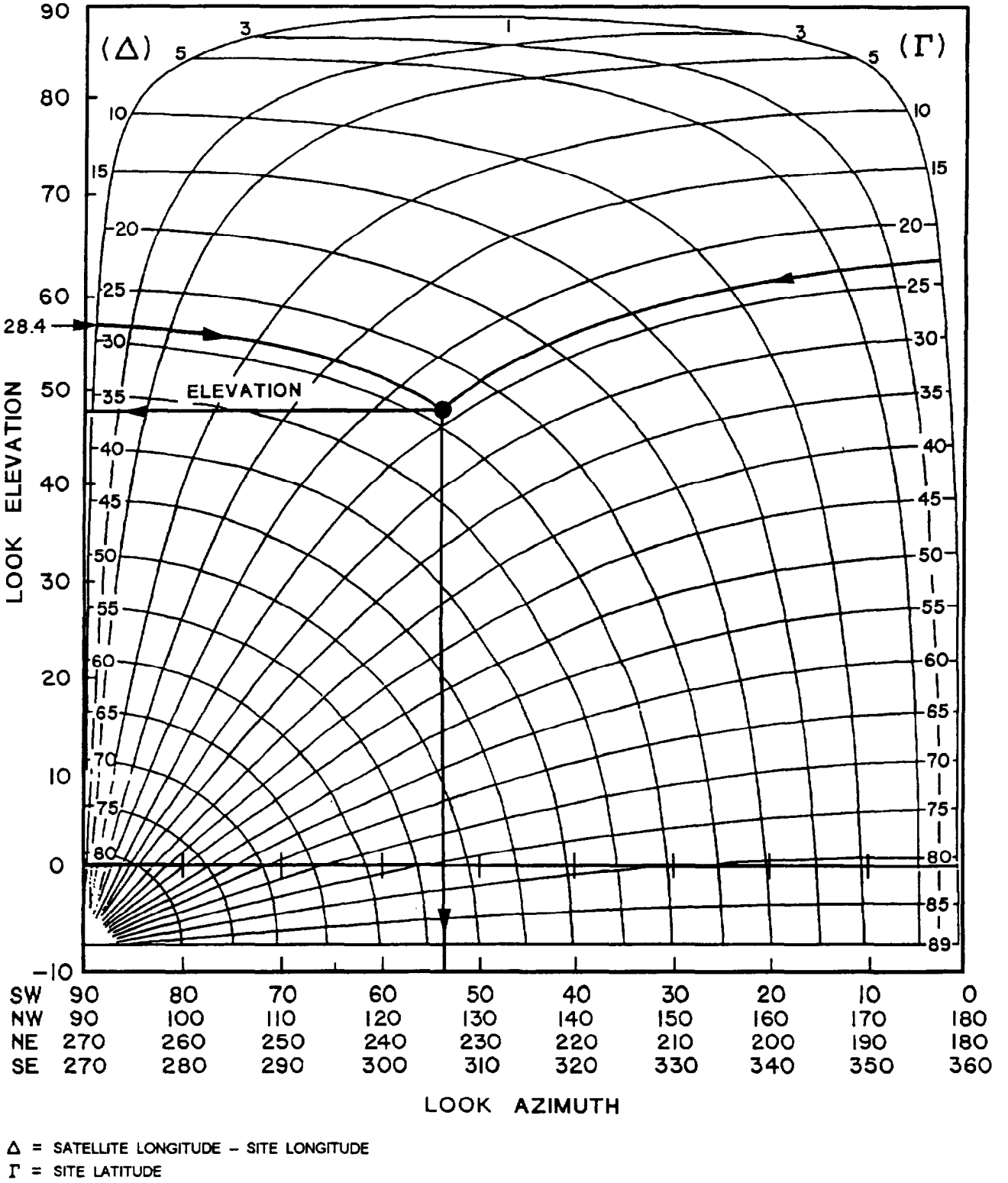


Figure 1-23.—Geostationary satellite antenna-aiming diagram.

- NW - When the receiver is north of the equator and west of the satellite's position

In the example shown on the diagram, azimuth and elevation angles are determined for the 75°W GOES

from a receiver site at 103.4°W longitude, 23.0°N latitude. The Δ value of 28.4° is the difference between 103.4° and 075.0°, ignoring the sign. The antenna elevation is about 48 degrees, and the azimuth on the NW scale is 126 degrees.

INTERNET

In recent years, the Internet has become a very efficient method of acquiring satellite imagery. The worldwide web is the fastest way to acquire a wide variety of real-time satellite imagery. NOAA/NEDSIS has its own website (NOAASIS) along with several private companies and universities. Of particular importance is that these sites can be reached aboard ships equipped with Internet access. FNMOC can also transmit satellite imagery over the military Internet (NIPRNET and SIPRNET). This imagery can then be viewed using Joint METOC Viewer (JMV) software with any computer system able to process the data. Details on the JMV and the NIPRNET/SIPRNET routing networks is covered in later modules. The Naval Research Laboratory in Monterey, California, has an outstanding Internet homepage that provides a tremendous amount of satellite imagery data. It contains general information relating to environmental satellites and provides guidance packages for new and experimental satellite products. The website also provides links to various other satellite imagery sources.

AUTODIN MESSAGE

The Automatic Digital Network (AUTODIN) is the U.S. Navy's most common method of transmitting message traffic between commands. Satellite images can also be sent via AUTODIN in greatly compacted form. This method is only used in rare cases, most often used by at-sea platforms with little or no environmental satellite reception capability and no Internet access. Portions ofreceived images that are of interest to a ship can be extracted, compacted, encoded for transmission, and sent via AUTODIN link to the ship from any other command (normally Meteorology and Oceanography centers). The AUTODIN encoded images are then available for reprocessing and display by the ship. Requests for satellite imagery via AUTODIN are carried out on a case-by-case basis. Requests should be limited to information that is essential to operations, as too much data will slow other AUTODIN message traffic.

REVIEW QUESTIONS

Q30. Which U.S. Government agency provides HF broadcasts of satellite imagery?

Q31. What type of satellite imagery is available from NODDS?

Q32. How is satellite imagery acquired by most shore-based weather stations?

Q33. What is the purpose of a satellite looper?

Q34. What is the advantage of APT direct-readout imagery?

Q35. How does the resolution between APT and HRPT data compare?

Q36. What type of information is available from the WEFAX broadcast?

Q37. What is the fastest way to acquire a wide variety of satellite imagery?

Q38. How can units with no environmental satellite reception capability or Internet access still receive satellite imagery?

SATELLITE RECEIVER SYSTEMS

LEARNING OBJECTIVES: Identify the two primary satellite receiver systems used to acquire direct-readout imagery and WEFAX products. Identify the operator's manuals that provide detailed instructions for use of the systems.

Two satellite receiver systems are routinely operated by Navy and Marine Corps weather observers. The AN/SMQ-11 system is used at major shore installations and aboard all aircraft carriers. Navy Mobile Environmental Teams (METs) use the optional satellite module of the IMOSS to receive satellite imagery.

AN/SMQ-11 METEOROLOGICAL DATA SET

The AN/SMQ-11 satellite receiver station is installed aboard most U.S. Navy ships staffed by Aerographer's Mates, at many Naval Meteorology and Oceanography Command activities, and in Marine Corps Mobile Meteorological Vans (METVANs). The ANISMQ-11 may receive, process, display, grid, and enhance DMSP imagery and both APT and HRPT

direct-readout imagery. The system can also receive WEFAX imagery, but cannot command a data download of stored HRPT data. The AN/SMQ-11 produces imagery on dry-silver film (which requires no chemicals for development), or by using a high-resolution laser printer.

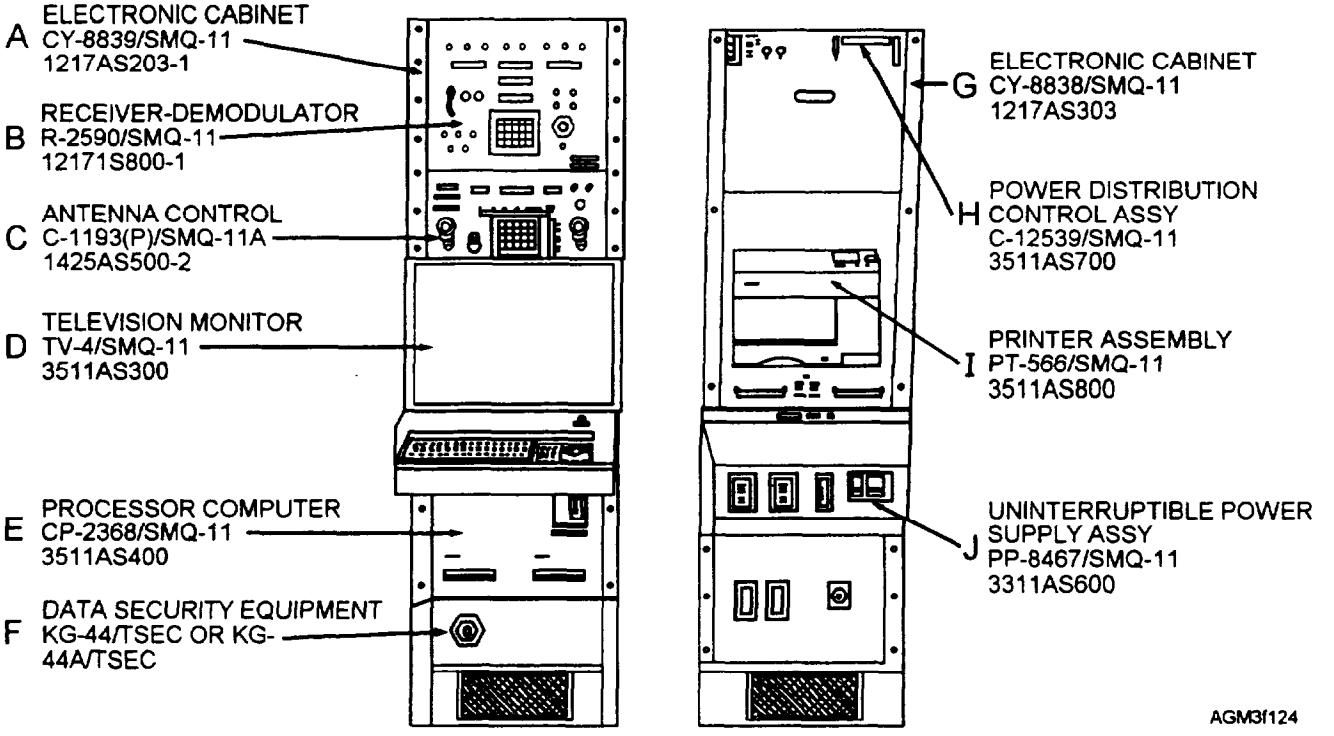
Figure 1-24 shows the two AN/SMQ-11 equipment cabinets that are installed inside the workspaces. Each AN/SMQ-11 is equipped with a Tactical Advanced Computer, Version Four (TAC-4), that includes a workstation, color monitor, an uninterruptible power supply, and a power distribution unit. The ANLSMQ-11B has a dual frequency array antenna (figure 1-25) and is normally installed on a rooftop ashore. Some systems are equipped with a multi-frequency array antenna (ANLSMQ-11C). The shipboard version of the AN/SMQ-11 contains additional circuits for control and stabilization of the antenna to compensate for ship motions. Operation of the ANISMQ-11 is described in detail in NAVAIR 50-30SMQ-11, *Organizational Maintenance with Illustrated Parts Breakdown, Receiver/Recorder Set, Meteorological Data, AN/SMQ-11*. This manual includes operator instructions.

At most sites, the AN/SMQ-11 satellite receiver system is cross connected to the Tactical Environmental Support System (TESS). Imagery received by the AN/SMQ-11 may be "called into" the TESS terminal for processing, display, and analysis. Additionally, much of the operation and control of the AN/SMQ-11 can be performed through the TESS keyboard.

The directional antenna of the AN/SMQ-11 system must be aimed at the satellites to receive either direct-readout imagery or GOES and WEFAX broadcasts. The aiming operation is performed automatically by the system, provided the ephemeris data has been entered properly for each polar-orbiting satellite, and the position data has been updated for the geostationary satellites.

IMOSS SATELLITE MODULE

The Interim Mobile Oceanography Support System (IMOSS) is a combination of three



A. Electronic Cabinet CY-8839/SMQ-11
B. Receiver-Demodulator R-2590/SMQ-11
C. Antenna Control C-l1933(P)/SMC-11
D. Television Monitor TV-4/SMQ-11
E. Processor Computer CP-2368/SMQ-11
F. Data Security Equipment KG-44/TSEC
G. Electronic Cabinet CY-8838/SMQ-11
H. Power Distribution Control Assembly C-12539/SMQ-11
I. Printer Assembly PT-566/SMQ-11
J. Uninterruptible Power Supply Assembly PP-8467/SMQ-11

Figure 1-24.—AN/SMQ-11 equipment cabinets.

Figure 1-25.—AN/SMQ-11 dual frequency array antenna.

subsystems, the main subsystem, the communications module subsystem (COMM MOD), and the satellite module subsystem (SAT MOD). Each subsystem consists primarily of a laptop computer that can be used as a stand-alone system, depending upon mission requirements. The main subsytem contains a multiple application software library dedicated to many aspects of METOC support. The IMOSS comes equipped with a printer.

The SAT MOD consists of a laptop computer that contains a built-in satellite receiver and processor. It also includes a VHF receiver/demodulator and two antennas. One antenna is an omnidirectional antenna used to copy APT signals and the other is used to copy signals from the WEFAX broadcast. The SAT MOD is equipped with special software modifications that can be used independently from the main IMOSS computer. Satellite imagery received via the satellite module may be transferred to the main IMOSS computer by using a 1.44MB data disk. All components are equipped with protective cases (fig. 1-26).

Because the APT antenna is omnidirectional, no antenna aiming is required to track polar-orbiting satellites or geostationary satellites. When the system is powered up, the receiver will automatically scan satellite frequencies, detect imagery signals, and acquire the imagery. The WEFAX antenna must be manually oriented toward the geostationary satellite during initial setup of the system. For planning, the system contains software that displays orbital predictions and line-of-sight receiver ranges for the polar-orbiting APT and geostationary satellite WEFAX transmissions. Menu options on the liquid crystal display (LCD) screen guide the operator

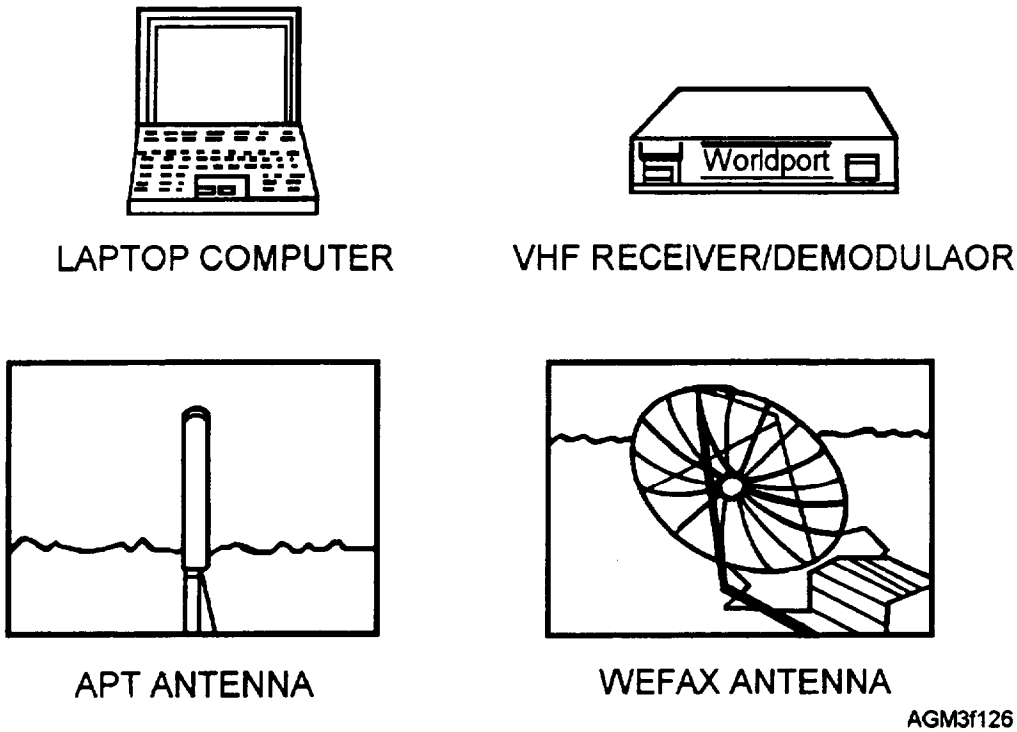


Figure 1-26.—Interim Mobile Oceanography Support System (IMOSS) satellite module.

through processing, gridding, and enhancement options for various APT direct-readout and WEFAX imagery.

The operator must update satellite ephemeris data for each polar-orbiting satellite at least once every 2 weeks. Selected prediction information from Part IV of the TBUS or NASA-2 line bulletins may be manually entered via the keyboard or copied directly from a data disk. Orbital-prediction information is available via message over the Automated Weather Network (AWN), by standard AUTODIN message, or by using a computer modem connection to various sources, such as the Internet.

Complete information on the operation of the IMOSS satellite module, including antenna orientation procedures, updating ephemeris data, gridding, and display of satellite imagery is contained in the IMOSS user's guide. The manual is provided with each module by the Naval Oceanographic Office.

REVIEW QUESTIONS

Q39. Which types of satellite imagery may be acquired by using the AN/SMQ-11?

Q40. Which types of satellite imagery may be acquired by using the IMOSS satellite module?

Q41. Which satellite antenna of the IMOSS satellite module must be manually oriented towards geostationary satellites?

EPHEMERIS INFORMATION

LEARNING OBJECTIVES: Identify the various orbital prediction bulletins and explain how they are obtained. Recognize how data from satellite orbital prediction bulletins is used to update user-operated satellite receivers.

One of the most critical operations on any of the direct-readout satellite imagery receiving systems is the updating of ephemeris data. *Ephemeris data* is information that describes the type, orientation, and shape of a particular satellite's orbit. Ephemeris data is critical to satellite tracking as it provides key information that allows you to determine where a satellite will be located at any given moment. This information is also used to allow the receiver system to predict where polar-orbiting satellites will be at any moment in relation to the location of the receiver site. More importantly, ephemeris information enables your receiver system to *earth-locate* the image, that is, to establish what area of the earth is depicted in an

image received from a polar-orbiting satellite. Once an image has been earth-located, you can then merge appropriate geographical boundaries and a latitude/longitude grid with the image. Without accurate placement of a grid system, even the clearest high-resolution images are nothing more than interesting pictures. Environmental applications require the analyst or forecaster to be able to determine where a feature is and how fast it is moving, which is an impossible task without an accurate reference grid.

Since geostationary satellites do not move relative to the earth, their ephemeris data does not need frequent updates. However, they are moved periodically and their positions are updated via special bulletins as necessary. These bulletins are posted on the Internet at the NOAASIS web site.

Several software programs are in use in various systems to automatically calculate polar-orbiting satellite orbits and antenna-aiming data. The AN/SMQ-11 system and the SAT MOD both perform these functions, but rather differently. TESS, which may be used to control the AN/SMQ-11, also has a separate orbital prediction function. Software upgrades are in development that will alleviate some of these differences.

In this section, we will discuss how to interpret various elements of ephemeris information from the most common polar-orbiting satellite prediction bulletins. The exact information required, as well as data entry methods for each system, are discussed in the individual operator's manuals.

Ephemeris data for each polar-orbiting satellite is available from several sources. Information for the NOAA satellites is available from the National Weather Service telecommunications center as NOAA APT Predict bulletins and from NASA as Two-Line Orbital Elements bulletins. Orbital information for the DMSP satellites and all foreign-operated, polar-orbiting satellites is available from the Naval Space Surveillance Center, Dahlgren, Virginia, as *C-Element Orbital Data* and *Satellite Equator Crossings* bulletins.

NOAA APT PREDICT BULLETINS (TBUS)

NOAA APT Predict bulletins, because of the message's data identifier TBUS, are more commonly referred to as TBUS data. These bulletins are routinely provided over the WEFAX broadcast and the automated weather network (AWN). They are also available on the meteorological/oceanographic data channel of the fleet multichannel communications broadcast, as well as via AUTODIN message. TBUS data can also be obtained from the Internet through the NOAASIS website.

The TBUS bulletins are in a special U.S. national code form. The code form is only used for orbital prediction information for satellites operated by the United States. Complete information on this code is available in the *NOAA KLM User's Guide.* Satellites in the TBUS bulletin are identified in the message header by name, such as NOAA 14, and by the U.S. satellite identification number, such as 37 for NOAA 12, and 38 for NOAA 14. In Part IV of the bulletin, the satellites are identified by an internationally recognized satellite number, such as 1994 089A for NOAA 14.

A separate NOAA APT predict bulletin is composed daily for each operational NOAA series satellite. TBUS 1 bulletins are used to indicate north to south (descending) daylight orbits, and TBUS 2 bulletins are used to indicate south to north (ascending) daylight orbits. Each bulletin is composed of six parts:

- Part I contains equator-crossing reference information.
- Day Part II contains satellite altitude and subpoint coordinates in 2-minute intervals for reference orbits over the Northern Hemisphere in the sunlight portion.
- Day Part III contains the altitude and subpoint coordinates for the portion of the reference orbits over the Southern Hemisphere in the sunlight portion.
- Night Part II contains 2-minute coordinates for the portion of the orbit over the Northern Hemisphere in the dark sector.
- Night Part III contains coordinates for the portion of the orbit over the Southern Hemisphere in the dark sector.
- Part IV contains high-precision orbital calculation elements, transmission frequencies, and remarks.

Parts II and III (day and night) are useful only when satellite orbits must be manually plotted and will not bediscussed further. TESS requires information from both Parts I and IV, while the SAT MOD and AN/SMQ-11 require only information from Part IV.

Table 1-2.—Typical NOAA APT Predict Bulletin

TBUS 2 KWBC 021900
APT PREDICT
MMDDSS
010538 NOAA 14
PART I
$0N_rN_rN_rN_r$ $0D_rD_rH_rH_r$ $0m_rm_rs_rs_r$ $Q_rL_oL_oL_oL_o$ Tmmss $LL_oL_oL_oL_o$
05551 00515 05539 02127 T0203 L2551 (Reference Orbit)
$N_4N_4N_4N_4H_4$ $H_4m_4m_4s_4s_4$ $Q_4L_oL_oL_oL_o$
55552 24353 12333 (Fourth Orbit)
$N_8N_8N_8N_8H_8$ $H_8m_8m_8s_8s_8$ $Q_8L_oL_oL_oL_o$
55590 53207 23461 (Eighth Orbit)
$N_{12}N_{12}N_{12}N_{12}H_{12}$ $H_{12}m_{12}m_{12}s_{12}s_{12}$ $Q_{12}L_oL_oL_oL_o$
55631 22021 33255 (Twelfth Orbit)
DAY PART II ...
DAY PART III ...
NIGHT PART II ...
NIGHT PART III ...
PART IV
AAAAAAAAA BBBBB CCCCCCCCCCCC DDEEFFGGHHIIIII JJJJJJ
1994 089A 15472 365064564372 971231013258362 1227653
KKKKKKKK LLLLLLLL MMMMMMMM NNNNNNNN OOOOOOOO PPPPPPPP
01020047 01020594 00098964 09699662 31704580 09902079
QQQQQQQQ RRRRRRRR SSSSSSSSS TTTTTTTTT UUUUUUUUU
26324050 07228814 P052955506 M049302836 M000000000
VVVVVVVVV WWWWWWWWW XXXXXXXXX YYYYYYYYY ZZZaaabbb cccc
M00803903 M00840889 P07331793 004218509 104094004 9449
ddddddddd eeeeeeeee fffffffff ggggggggg hhhhhhhh $L_oL_oL_oL_oL_oL_oL_o$
0000500000 M00272363 P00100495 P00508212 19428046 13702451
iiiiii jjjjjj kkkkkk llllll mmmmmm nnnnnn oooooo
102897 M00110 121597 M00700 120197 P00010 032498
APT TRANSMISSION FREQUENCY 137.62 MHZ
HRPT TRANSMISSION FREQUENCY 1707.0 MHZ
BCN (BEACON) DSB FREQUENCY 137.77 MHZ
APT DAY/NIGHT 2,4. VIS CH 2 /0.725 TO 1.0/ AND IR CH 4 /10.5 TO 11.5/ XMTD
DURING S/C DAY. IR CH3 /3ND IR CH 4 /10.5 TO 11.5/ XMTD
DURING S/C NIGHT. DCS CLK TIME YR/DA/TIM 1995 021 79186.656.
BT

Table 1-2 shows a typical TBUS bulletin with the information in Parts II and III deleted. We have added a symbolic code form in italics to help you understand what information is included in the message. Table 1-3 references this symbolic code form and identifies the information. We have concentrated on the information needed for input to the various ephemeris update programs currently in use. Appendix II is a diagram of the octants of the globe.

Directly under the APT Predict line is an identifier for the date of the beginning of the prediction period and the U.S. satellite identification number. In our example in the table, 0105038 means the prediction period begins on January 05 (0105) for satellite 38 (NOAA 14). The orbital predictions are carried out to several days. Note that the message date-time-group 021900 shows that the bulletin is transmitted 3 days before the prediction period covered by the message.

Table 1-3.—Explanation of Important TBUS Bulletin Elements

TBUS MESSAGE HEADER		
MMDDSS: Prediction start- *MM*=Month, *DD*=Day, *SS*=U.S. Satellite number		
TBUS MESSAGE PART I		
$0N_rN_rN_rN_r$:	0	= Code group indicator for first three groups $N_rN_rN_rN_r$= reference orbit #
$D_rD_rH_rH_rm_rm_rs_rs_r$:		Reference orbit equator crossing time (UTC): D_rD_r= day, H_rH_r= hour, m_rm_r= minute, s_rs_r= second
$Q_rL_oL_oL_oL_o$:	Q_r	= Octan t satellite is entering after crossing equator on reference orbit $L_oL_oL_oL_o$ = Reference orbit equator crossing longitude in degrees and hundredths of a degree
Tmmss		Nodal period: *T* = indicator, *mm* = minutes, *ss* = seconds (hundreds grou will not be included; 100 min. 13 sec. will be coded as 0013)
$LL_oL_oL_oL_o$:		Nodal Increment: *L* = indicator, $L_oL_oL_oL_o$ = degrees and hundredths of degrees longitude between successive equator crossings
$N_4N_4N_4N_4$		Orbit # of 4th (8th or 12th) orbit after reference orbit
$H_4H_4m_4m_4s_4s_4$:		Time (UTC) in hours, minutes, and seconds of satellite equator crossing 4th, (8th or 12th) orbit after reference orbit
$Q_4L_oL_oL_oL_o$:	Q_4	= Octant satellite is entering after crossing equator on 4th (8th or 12th) orbit after reference orbit $L_oL_oL_oL_o$ = Equator crossing longitude after reference orbit
TBUS MESSAGE PART IV		
AAAAAAAAA		= International satellite identification
BBBBB		= Orbit number at epoch
CCCCCCCCCCC		= Time of the first ascending node, in days, from the beginning of the year (9 decimal places)
DDEEFFGGHH		= Epoch calendar date/time: *DD*= Year, *EE*= month, *FF*= day,
IIIII		= *GG*= hour, HH= minutes, and *IIIII*= seconds (3 decimal places).
JJJJJJ		= Apparent Greenwich Hour Angle at epoch (4 decimal places)
KKKKKKKK		= Mean period of anomaly (min) (4 decimal places
LLLLLLLL		= Nodal period (min) (4 decimal places)
MMMMMMMM		= Eccentricity (8 decimal places)
NNNNNNNN		= Argument of perigee (deg) (5 decimal places)
OOOOOOOO		= Right Ascension of ascending node (deg) (5 decimal places)
PPPPPPPP		= Inclination (deg) (5 decimal places)
QQQQQQQQ		= Mean anomaly (deg) (5 decimal places)
RRRRRRRR		= Semi-major axis of orbit (km) (3 decimal places)
SSSSSSSSS		= *Epoch X position component (km) (4 decimal places)
TTTTTTTTT		= *Epoch Y position component (km) (4 decimal places)
UUUUUUUUUU		= *Epoch Z position component (km) (4 decimal places)
VVVVVVVVV		= *Epoch X velocity component (km/sec) (6 decimal places)
WWWWWWWWW		= *Epoch Y velocity component (km/sec) (6 decimal places)
XXXXXXXXX		= *Epoch Z velocity component (km/sec) (6 decimal places)
YYYYYYYYY		= Ballistics coefficient CD-A/M (m^2/kg), to eight decimal places
ZZZ		= Daily solar flux value (10.7 cm) 10^{-7} W/m^2
aaa		= 90-day running mean of solar flux 10^{-7} W/m^2
bbb		= Planetary magnetic index (2×10^{-5} gauss)
cccc		= Drag modulation coefficient, to four decimal places
ddddddddd		= Radiation pressure coefficient (m^2/kg), to ten decimal places
eeeeeeee		= *Perigee motion (deg/day) (5 decimal places)
fffffff		= *Right Ascension of the Ascending-Node motion (deg/day) (5 decimal places)
ggggggggg		= *Rate of change of mean anomaly at epoch (deg/day), (2 decimal places)
hhhhhhhh		= Equator crossing longitude of the epoch reference orbit measure as East longitude, (5 decimal places)
iiiiii		= Month, date and year (MMDDYY) of last TIP clock correction
jjjjjj		= *Clock error after last correction measured in seconds (to three decimal places)
kkkkkk		= Month, date and year (MMDDYY) of current clock error
llllll		= *Current clock error measured in seconds (three decimal places)
mmmmmm		= Month, date and year (MMDDYY) of the measured clock error rate
nnnnnn		= *Clock error rate expressed as milliseconds/day
oooooo		= Month, date and year (MMDDYY) of next TIP clock correction (000000 if unknown)
* signed values; *P* for positive, *M* for negative		

In the TBUS bulletin Part IV, all information necessary to calculate a satellite's orbit and variations in the orbit is provided. This information includes an epoch orbit number, two forms of an epoch date, position and velocity coordinates, the nodal period, and anomaly values used to determine the change in position of the satellite over any period of time.

SAT MOD Ephemeris Updates

Like the TESS, the SAT MOD may update ephemeris information by reading a TBUS message file. If the appropriate TBUS bulletin is not available directly from a disk file, the system may be updated with manual entries by using information in the TBUS bulletins. Only certain elements from each TBUS bulletin are required for each satellite in the SAT MOD. The resulting ephemeris files need only be updated every 2 weeks. Instructions for imputing TBUS bulletin data is contained in the IMOSS user's guide.

TESS Ephemeris Updates

TESS allows satellite ephemeris data files to be updated manually by entering selected data via the keyboard. TESS, interfaced with a communications system, may be directed to read a saved TBUS message file to automatically update ephemeris information. TESS may only use each particular TBUS bulletin during a 7-day valid period following the prediction date; in this case January 05 to January 12. Since predict bulletins are sent out daily, TESS may store more than one file of ephemeris information for each satellite, and prediction periods may overlap.

AN/SMQ-11 Ephemeris Updates

The AN/SMQ-11 does not have the capability to interpret imported TBUS messages to update its ephemeris files. Various parameters from the TBUS bulletin Part IV may be manually entered. The SMQ-11 requires the epoch calendar date-time-group be entered vice the epoch decimal date-time-group.

NASA TWO-LINE DATA

Another predict message is the NASA Two-Line Orbital Elements (TLE) bulletin. This bulletin contains orbital information very similar to Part IV of the TBUS bulletin. The message is divided into 16 elements and can be input into the SAT MOD and AN/SMQ-11 in lieu of TBUS data. Keep in mind that while similarly named elements appear in both the NASA Two-Line and TBUS bulletins, the values are NOT interchangeable between systems to compute satellite tracks. Table 1-4 is an example of a NASA Two-line bulletin and table 1-5 is a description of the information.

NAVSPASURCEN ORBITAL DATA

The Naval Space Surveillance Center (NAVSPASURCEN) in Dahlgren, Virginia, tracks all U.S. and foreign-operated satellites and space debris. Navy and Marine Corps satellite-receiver system users may request message support for satellite tracking information. The AN/SMQ-11 contains software designed to use and interpet separate messages of data known as *Satellite Equator Crossings.* TESS uses a product known as *C-Element Orbital Data* to calculate orbits for the AN/SMQ-11.

A Satellite Equator Crossings message contains information similar to TBUS Part I. The AN/SMQ-11 needs to be updated frequently (about every 2 days) by using the information from this product. The message contains information on all U.S. and foreign-operated environmental satellites. Table 1-6 contains a portion of a Satellite Equator Crossings message with explanations of the elements required to update the AN/SMQ-11. The underlined elements are required input.

C-Element orbital data also contains information similar to Part IV of the TBUS bulletin. See table 1-7 for an example of a typical message containing C-element orbital data and table 1-8 for an explanation of the data. In the C-element orbital data message, each line of data is repeated three times. This is done so that

Table 1-4.—Sample NASA Two-line bulletin

```
NOAA 14
1 23455U 94089A 95222.82483495 .00000053 00000-0 53646-4 0 2755
2 23455 98.9047 164.9161 0010620 42.0812 318.1174 14.11526152 31526
```

Table 1-5.—Explanation of NASA Two-line bulletin elements

NOAA-14	Satellite name
1 23455U	1- Message line 1 23455- Satellite number 23455
94089A	94- Launch year 1994 089- Launch number 89 A- Launch piece A (not in multiple pieces)
95222.82483495	95- Epoch year 1995 222.82483495- Julian day 222 and fraction
.00000053	First time derivative of the mean motion (decay rate, plus sign implied)
00000-0	Second time derivative of the mean motion
53646-4	BSTAR drag term
0	Ephemeris type (zero)
2755	Element number 275, 5- Check sum
2 23455	2- Message line 2 223455- Satellite number 23455 (repeated)
98.9047	Orbit inclination 98.9047 degrees
164.9161	Right ascension of ascending node 164.9161 degrees
0010620	Eccentricity .0010620
42.0812	Argument of perigee 042.0812 degrees
318.1174	Mean anomaly 318.1174 degrees
14.11526152	Mean motion 14.11526152 revolutions per day
31526	3152- Satellite revolution 3152 at epoch 6- Check sum

Table 1-6.—A Portion of a NAVSPASURCEN Satellite Equator Crossings Message

FM NAVSPASURCEN DATA DAHLGREN VA
TO USS NOBODY
BT
UNCLAS //N03840//
SUBJ: SATELLITE EQUATOR CROSSINGS
ASC EQUATOR CROSSINGS FOR SATELLITE 16969 NOAA 10
ALT/KM INCLINATION NODAL PERIOD NODAL INCR
810 98.59575 101.2068 25.30

HRMNSE LONG DAY/YR REV
011022 86.6W 169/97 19473 → *Orbit # of first crossing*
025134 111.9W → *Consecutive day (Julian day) and year of first orbit*
043246 137.2W
061359 162.5W
071511 172.2E

→ *Ascending node equator crossing longitude*

→ *Ascending node equator crossing time (hours, minutes, seconds UCT)*

(Message continues with equator crossing times (UCT) and east/west longitudes for several crossings, and then provides similar information for many other satellites)

Table 1-7.—C–Element Orbital Data Message

```
ZNR UUUU
R 041727Z MAR 97
FM NAVSPASURCEN DAHLGREN VA
TO XXXXXX
BT
UNCLAS //N03840//
16969.2907047.8352017.99938.0013459.5727927.8105893.2739137970307
16969.2907047.8352017.99938.0013459.5727927.8105893.2739137970307
16969.2907047.8352017.99938.0013459.5727927.8105893.2739137970307
19531.0665307.8281567.99929.0011969.5853780.5828128.2749230970307
19531.0665307.8281567.99929.0011969.5853780.5828128.2749230970307
19531.0665307.8281567.99929.0011969.5853780.5828128.2749230970307
21263.3456862.8339169.00000.0068626.5838341.3961844.2740511970306
21263.3456862.8339169.00000.0068626.5838341.3961844.2740511970306
21263.3456862.8339169.00000.0068626.5838341.3961844.2740511970306
BT
```

any "hits" on the signal during transmission may be detected and corrected by the user. Because of this format, the message is sometimes called *"3-line Charlie data."* The periods separate individual data elements, and in most cases, indicate a decimal point.

Be aware that the NAVSPASUR-assigned identification numbers do not correspond to either U.S. satellite numbers or to the international satellite identification. The Satellite Equator Crossings message provides both NAVSPASURCEN's satellite number and the satellite name, such as 21263, NOAA 12.

REVIEW QUESTIONS

Q42. What is the purpose of ephemeris data?

Q43. What are the most common methods of obtaining TBUS data?

Q44. What information is contained in Part I of the TBUS message?

Q45. What general information is contained in Part IV of a TBUS message?

Q46. What is the second element of a NASA Two-line message?

Table 1-8—Format of C-Element Data

C-ELEMENT DATA LINE			
AAAAA BBBBBBB CCCCCCC DDDDD EEEEEEE FFFFFFF GGGGGGG HHHHHHHIIIII 16969.2907047.8352017.99938.0013459.5727927.8105893.2739137970307			
ELEMENT INTERPRETATION			
AAAAA	=	NAVSPASURCEN Satellite number	(example: #16969)
BBBBBBB	=	Raw mean anomaly (7 decimal places)	(example: 0.2907047)
CCCCCCC	=	Raw mean motion (7 decimal places)	(example: 0.8352017
DDDDD	=	Raw orbital decay (5 decimal places)	(example: 0.99938)
EEEEEEE	=	Orbital eccentricity (7 decimal places)	(example: 0.0013459)
FFFFFFF	=	Raw perigee (7 decimal places)	(example: 0.5727927)
GGGGGGG	=	Raw ascension (7 decimal places)	(example: 0.8105893)
HHHHHHH	=	Raw inclination (7 decimal places)	(example: 0.2739137)
IIIII	=	Epoch date in form YYMMDD (year, month, day)	(example: 97/03/07)

Q47. How often should equator-crossings ephemeris data be updated for the AN/SMQ-11?

Q48. Where does ephemeris data for DMSP satellites originate?

SUMMARY

In this chapter we have discussed the various applications of satellite data and some basic terms used to discuss satellite orbits and satellite imagery acquisition. We have identified several types of environmental satellites and explained the advantages and disadvantages of each. We have also discussed the use of various types of satellite imagery, and also introduced you to some basic imagery enhancement techniques. We described several methods used to acquire satellite imagery, and the basic equipment used at Navy and Marine Corps shore stations and aboard ships to receive imagery. We also discussed some of the bulletins that provide the orbital data required as input for satellite receiver-processors.

ANSWERS TO REVIEW QUESTIONS

A1. *Zero degrees (0°).*

A2. *Geostationary, earth-synchronous, or geosynchronous.*

A3. *Ascending-node.*

A4. *The satellite's orbit is synchronized with the movement of the sun across the earth's surface.*

A5. *0200 local.*

A6. *Major changes in a satellite's apogee and perigee positions are caused by the shape of the earth, and the gravitational pull of the earth, sun, and moon.*

A7. *Atmospheric sounders provide vertical temperature and moisture profiles, and atmospheric stability data.*

A8. *Geostationary satellites are ideal for making large-scale, frequent observations over a fixed geographical area*

A9. *GOES East.*

A10. *Polar-orbiting.*

A11. *Because of their relatively low-altitude orbits, polar-orbiting satellites provide higher resolution data than geostationary satellites. They also provide imagery for the high-latitude and polar regions.*

A12. *2700 km (1500 nmi).*

A13. *Fleet Numerical Meteorology and Oceanography Center (FNMOC).*

A14. *METEOSAT*

A15. *A radiometer.*

A16. *The sensor with 1 kilometer spatial resolution.*

A17. *The cold object.*

A18. *Longwave radiation.*

A19. *Red.*

A20. *Sand.*

A21. *Infrared imagery is available day and night. It is also an excellent tool for oceanographic analysis and is also helpful for identtfiing upper-level features.*

A22. *White.*

A23. *Relatively light gray shades.*

A24. *Water vapor imagery produces better definition of the moisture distribution and circulation patterns in the upper atmosphere.*

A25. *An enhanced satellite image provides better definition, which allows the user to view specific details.*

A26. Too much definition in an enhancement curve may make the the imagery difficult to interpret.

A27. A split enhancement curve.

A28. Sector identification information.

A29. 10°C.

A30. U.S. Coast Guard.

A31. DMSP.

A32. The GOES-TAP system.

A33. A satellite looper stores and displays a series of satellite images over the same area, which, in turn, shows the movement of cloud and weather systems.

A34. APT satellite transmissions provide real-time data and are relatively inexpensive to obtain.

A35. APT is at I-kilometer resolution and HRPT is at 1-kilometer resolution.

A36. Low- and high-resolution imagery meteorological and oceanographic charts, TBUS data, and operational messages.

A37. The Internet.

A38. AUTODIN message.

A39. DMSP, APT and HRPT (NOAA), and WEFAX.

A40. Both APT (NOAA) and WEFAX

A41. The WEFAX antenna.

A42. Ephemeris data allows satellite receiver systems to predict when and where satellites will be at any given moment. It also allows receiver systems to earth-locate satellites, which aids in gridding.

A43. TBUS data can be obtained via AUTODIN message, AWN the fleet multichannel broadcast, or via the Internet.

A44. Part I of the TBUS message contains equator-crossing reference information.

A45. Part IV of the TBUS message contains high-precision orbital calculation elements, transmission frequencies, and remarks.

A46. The launch year, launch number, and number of launch pieces.

A47. About every 2 days.

A48. Naval Space Surveillance Center, Dalhgren, Virginia

CHAPTER 2

WEATHER RADAR

INTRODUCTION

Since the late 1940's, radar has been used to track weather systems. Subsequent advances were made in radar transmitters, receivers, and other system components. However, with the exception of transistor technology, few changes were made to basic weather radar systems through the 1970's. In the late 1970's, work began on the "next-generation" of weather radar (NEXRAD) using *Doppler* technology. The use of Doppler technology enabled weather radar systems to not only detect meteorological targets with greater detail, but also measure target motion and velocity. By the mid 1980's, a new weather radar that used this technology was introduced. This system is known as the weather surveillance radar-1988-Doppler, or WSR-88D.

WSR-88D systems have been installed at several Navy and Marine Corps shore-based weather stations. Even if you do not have a WSR-88D at your command, almost all weather radar information you will receive is derived from Doppler radar. Thus, it is important that you understand basic Doppler theory and the WSR-88D system.

In this chapter we discuss the Doppler weather radar (WSR-88D). We begin with a general explanation of electromagnetic energy and radar propagation theory followed by a discussion of Doppler radar principles. We will then concentrate on the configuration and operation of the WSR-88D system. Finally, we complete the chapter with a discussion of the advantages and limitations of WSR-88D products, and the publications associated with the system.

ELECTROMAGNETIC ENERGY

LEARNING OBJECTIVES: Describe the properties of electromagnetic energy. Define electromagnetic wave, electromagnetic spectrum, wavelength, amplitude, frequency, and Rower.

Understanding the fundamentals of electromagnetic (EM) energy will enhance your ability to use weather radar. No matter how sophisticated the radar system, theoretical limitations always exist. This background knowledge will also help you to understand the operation of the WSR-88D and to effectively use the products it produces. In the following text, we will begin with a general discussion of electromagnetic energy followed by a description of several properties related to electromagnetic waves.

ELECTROMAGNETIC WAVES

As discussed in chapter 1 of this module, all things (whose temperature is above absolute zero) emit radiation. Radiation is energy that travels in the form of waves. If this energy were visible, it would appear as *sine* waves, with a series of troughs and crests (fig. 2-1). Because radiation waves have electrical and

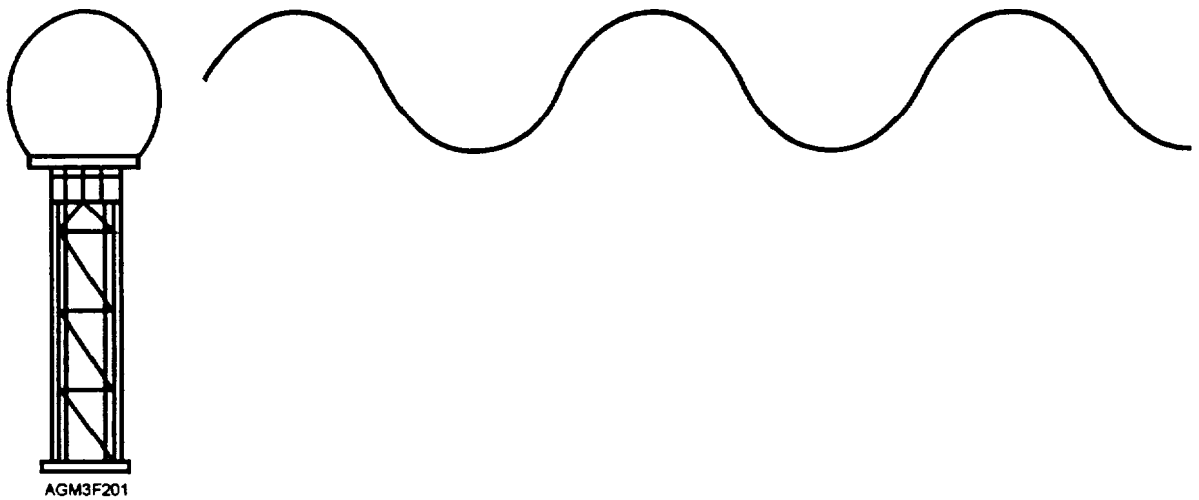


Figure 2-1.—Electromagnetic energy as sine waves.

magnetic properties, they are called *electromagnetic waves.*

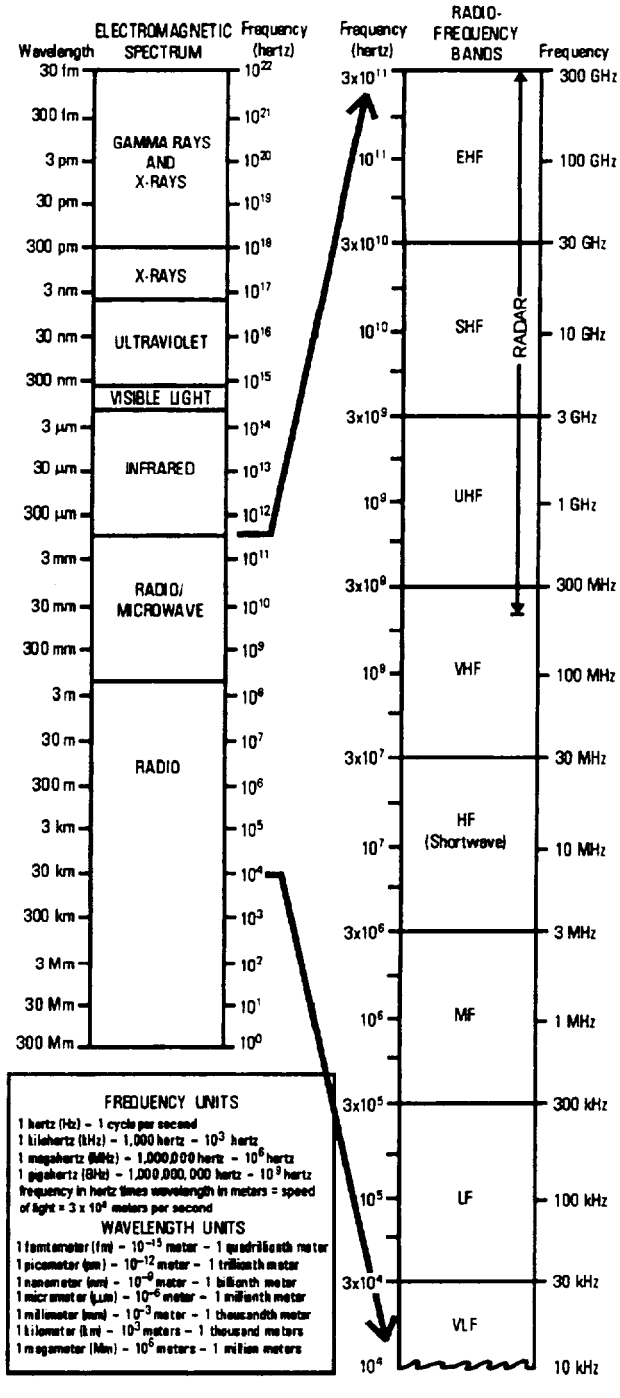
Most of the electromagnetic energy on the earth originates from the sun. The sun's electromagnetic waves propagate through space and into the earth's atmosphere. The sun actually radiates electromagnetic energy at several different wavelengths and frequencies, ranging from gamma rays to radio waves. Collectively, these wavelengths and frequencies make up the *electromagnetic spectrum,* as shown in figure 2-2. Here on earth, radar systems transform electrical energy into electromagnetic energy in the form of *radio waves.*

Each region of the electromagnetic spectrum can be subdivided into narrower *frequency bands* as shown in figure 2-2. As you can see, electromagnetic waves from radar energy normally fall between 200 MHz and 300 GHz. A radar transmitter emits this energy into the atmosphere through an antenna. While only a fragment of the energy returns, it provides a great deal of information. The entire process of energy propagating through space, striking objects, and returning occurs at the speed of light. Targets struck by electromagnetic energy are said to have been *radiated,* and the return signals they produce are called *radar echoes.*

PROPERTIES OF ELECTROMAGNETIC WAVES

An electromagnetic wave consists of two fields, an electrical field and a magnetic field, which are perpendicular to each other and to the direction of propagation of the wave front *(fig. 2-3). Polarization* refers to the orientation of the electrical field component of an electromagnetic wave. Polarization can be either linear or circular. With linear polarization, the electromagnetic waves are either horizontally or vertically polarized relative to the earth's surface (fig. 2-3).

Most weather radars, including the WSR-88D, are horizontally polarized. There are two major benefits to this. The first is that energy returns from man-made ground targets that have a greater vertical extent than horizontal extent (like buildings) are greatly reduced. The second benefit relates to the returned energy from raindrops. Since raindrops tend to flatten as they fall, the surface area that the radar is able to detect increases, thus increasing energy return. Other important terms relating to electromagnetic waves you need to know are wavelength, amplitude, frequency, and power.



Band Designation	Nominal Frequency	Nominal Wavelength
HF	3-30 MHz	100-10 m
VHF	30-300 MHz	10-1 m
UHF	300-1000 MHz	1-0.3 m
L	1-2 GHz	30-15 cm
S	2-4 GHz	15-8 cm
C	4-8 GHz	8-4 cm
X	8-12 GHz	4-2.5 cm
K_u	12-18 GHz	2.5-1.7 cm
K	18-27 GHz	1.7-1.2 cm
K_a	27-40 GHz	1.2-0.75 cm
mm	40-300 GHz	7.5-1 mm

AGM3F202

Figure 2-2.—The electromagnetic spectrum.

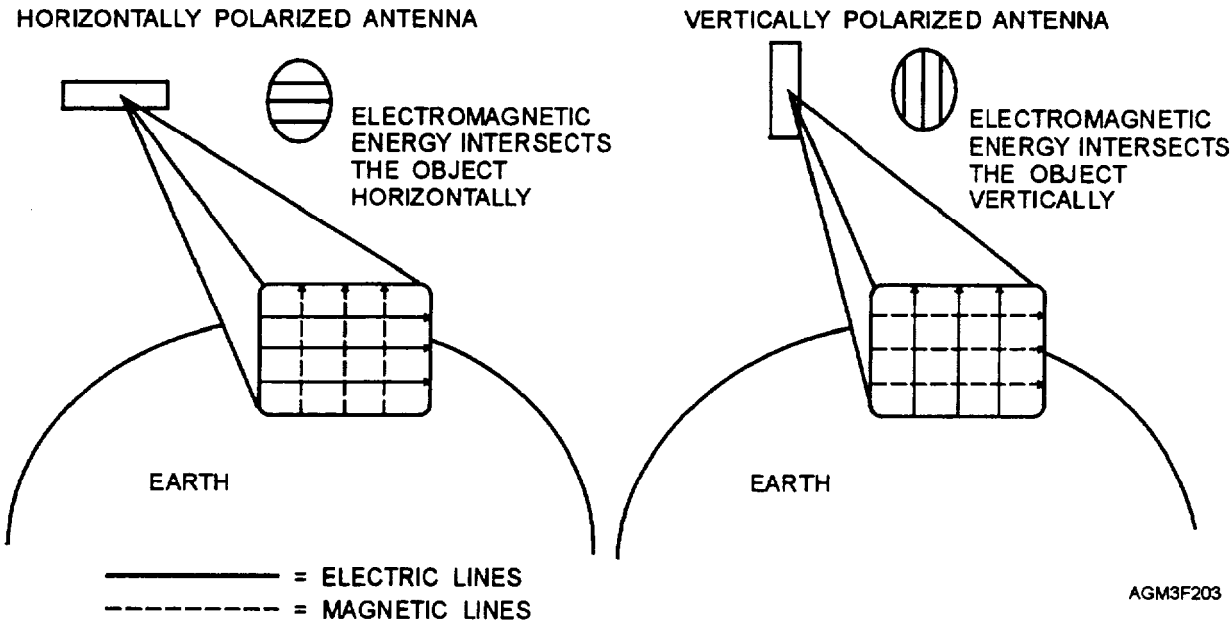


Figure 2-3.—Horizontally and vertically polarized electromagnetic waves.

Wavelength

The distance from wave crest to wave crest (or trough to trough) along an electromagnetic wave's direction of travel is called wavelength. Each measurement equals one complete wave, or wave cycle, and is typically expressed in centimeters. Each wavelength can also be described in terms of degrees, with one wavelength equal to 360° (fig. 2-4). This concept will become very important later, when we discuss Doppler radar.

As radar energy is emitted into the atmosphere, it encounters particles of dust, dirt, and salts, in addition to water vapor and precipitation. Collectively, these are known as scatterers, and they have an important effect on radar effectiveness. Wavelength plays a critical role in a weather radar's ability to see scatterers, that is, water droplets. Shorter wavelengths provide more detail and allow detection of small droplets, while longer wavelengths are best for larger targets, such as precipitation from rain showers and thunderstorms. It is important that a radar wavelength

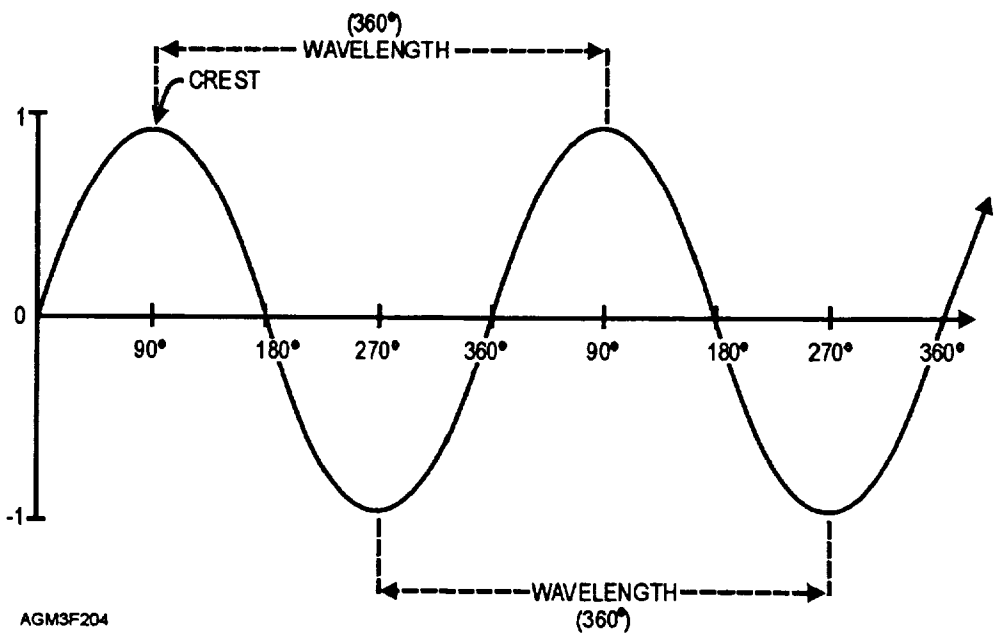


Figure 2-4.—Wavelength of an electromagnetic wave.

be short enough to detect fine scatterers without sacrificing severe weather detection abilities.

Amplitude

Wave *amplitude* is simply the wave's height (from the midline position) and represents the amount of energy or power contained within the wave. Simply put, greater amplitude means more power. Amplitude is usually expressed as some fraction of a meter (fig. 2-5).

Frequency

Frequency refers to the number of completed wave cycles per second. Radar frequency is expressed in units of hertz (Hz); one hertz being equal to one cycle per second. Frequency and wavelength are closely related as a change in one has a direct impact on the other. Essentially, higher frequency transmitters produce shorter wavelengths and lower frequency transmitters produce longer wavelengths. All wave characteristics in some way affect radar power. When more energy is available to strike targets, both signal strength and data reliability are increased and the radar performs more efficiently.

Electromagnetic waves can be described in terms of either frequency or wavelength. Looking back at figure 2-2, you can see the function of frequency versus wavelength.

Power

Power is the rate at which energy is used, With electromagnetic energy, the decibel system is used to compare two power values. A decibel, abbreviated "dB" is one tenth of a bel, the fundamental unit. The decibel system is useful for comparing power values that differ greatly, such as transmitter and receiver power. Values for dB are measured logarithmically, not linearly. With this in mind, you must be aware that every change of 3 dB corresponds to a *doubling (or halving)* of power. Doppler reflectivity values, which will be discussed later, are indicated by the abbreviation "dBZ."

REVIEW QUESTIONS

Q1. What is an electromagnetic wave?

Q2. Radar energy occupies what portion of the electromagnetic spectrum?

Q3. Wavelength is usually measured in what units?

Q4. How does wavelength affect a radar's ability to detect different types of targets?

Q5. Define radar frequency.

Q6. Given a frequency of 200 MHz and a frequency of 100 GHz, which one has a shorter wavelength?

Q7. How can different radar power values be compared?

BASIC RADAR CONFIGURATION

LEARNING OBJECTIVES: Define reflectivity. Identify the major parts of a radar system. Define radar sensitivity.

The acronym RADAR stands for RAdio Detection And Ranging. Radio waves, like light waves, are reflected from objects. The term *reflectivity* refers to the amount of energy returned from an object and is dependent on the size, shape, and composition of the

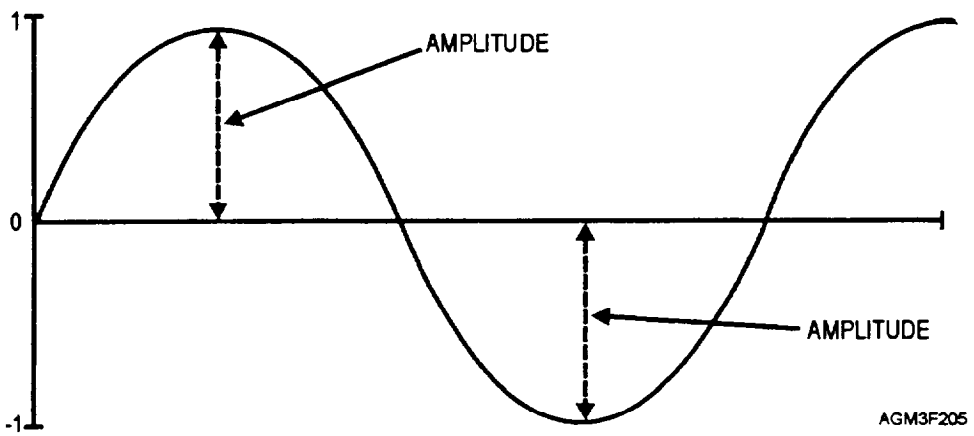


Figure 2-5.—Amplitude of an electromagnetic wave.

object. Through short bursts of radio EM energy, weather radar equipment displays the location and intensity (reflectivity) of meteorological targets such as rain showers and thunderstorms.

Figure 2-6 is a block diagram for a simple radar system that consists of the following components:

- A modulator that tells the transmitter when to transmit and for what duration.
- A transmitter that generates power.

An antenna that concentrates the radiated power into a shaped beam, which points in the desired direction and collects the echo signal for delivery to the receiver.

- A duplexer that connects the transmitter to the antenna during the transmission of the radiated pulse and connects the receiver to the antenna during the time between radiated pulses.
- A receiver that amplifies the weak echo signals picked up by the antenna to a level sufficient to display them.
- A signal processor that evaluates the signal from the receiver.
- A visual display unit that presents the information contained in the echo signal to an operator for interpretation.

Of prime importance concerning all these components is the radar's *sensitivity.* A radar's sensitivity, or signal to noise ratio, is a measure of the interference generated by the radar (self noise) against the minimum signal it is able to detect.

REVIEW QUESTIONS

Q8. What is meant by the term "reflectivity"?

Q9. Which part of a radar system shapes energy into a beam?

Q10. What is meant by the term "radar sensitivity "?

PRINCIPLES OF RADAR PROPAGATION

LEARNING OBJECTIVES: Distinguish various radar pulse characteristics, including pulse length, listening time, range ambiguity, range folding, and pulse volume. Define range resolution and pulse repetition frequency. Compute Rmax. Recognize the effects of beamwidth, beam broadening, and sidelobes on radar energy. Define azimuthal and range resolution.

Rather than transmit one long continuous wave (CW), weather radar uses short, powerful bursts of energy called pulses. Pulsed energy travels along a focused path called a beam, and occupies a specific amount of space. Pulses are separated by silent periods that allow the antenna to listen for a return pulse. The information gained from these pulses is critical in

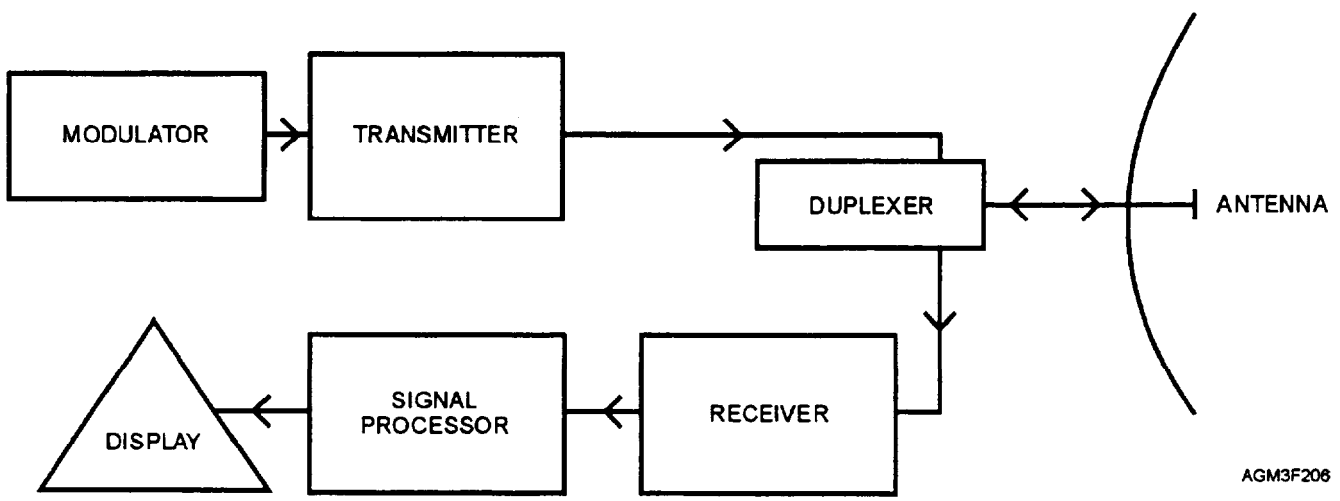


Figure 2-6.—Block diagram for a simple radar system.

determining target size, strength, and location (fig. 2-7).

RADAR PULSE CHARACTERISTICS

Radar pulses travel at the speed of light (186,000 miles per second). Thus, the distance to a target can easily be calculated by monitoring a pulse's elapsed time from transmission until its return. Half the distance traveled by the pulse determines the target's range from the antenna.

Pulse Length

Pulse length (or pulse duration) is the measurement taken from the leading to trailing edge of a pulse and is a good indicator of the amount of power contained within the pulse (fig. 2-7). Generally, longer pulses emitted from a radar return more power, thus increased target information and data reliability. Longer pulses have the disadvantage in that fine details within the return echo may be lost. Pulse length is usually expressed in microseconds, but is also measured in kilometers. The WSR-88D incorporates a variable pulse length that may be as short as 1.57 microseconds (1,545 feet). Important aspects ofaradar pulse include minimum range, range resolution, and pulse repetition frequency.

MINIMUM RANGE.—Pulse length determines a radar's minimum range or how close a target can get to the antenna without adversely affecting operations. Minimum radar range is defined as any distance greater than one-half the pulse length. In other words, targets more than one-half pulse length from the antenna can be correctly processed, while approaching targets that get too close pose serious problems. If targets come within one-half pulse length or less of the antenna, the pulse's leading edge will strike the target and return **before** the radar can switch into its receive mode. Some portion of the return energy is lost and the radar may become confused and discard the pulse.

RANGE RESOLUTION.—A radar's resolution is its ability to display multiple targets clearly and separately. Range resolution refers to targets oriented along the beam axis as viewed from the antenna's position. Longer pulses have poorer range resolution. Targets too close together lose definition and become blurred. They must be more than one-half pulse length apart or they will occupy the pulse simultaneously and appear as a single target. The problem of range resolution will be discussed in more detail later.

PULSE REPETITION FREQUENCY (PRF).—PRF is the **rate** at which pulses are transmitted (per second). It controls a radar's maximum effective range by dictating the duration of its listening time. Increased PRF speeds the rate at which targets are repeatedly radiated. This increased sampling results in greater target detail, but the maximum range of the radar is reduced because of the shorter periods between pulses. The WSR-88D can emit anywhere from 318 to 1304 pulses per second. It has a maximum range of approximately 250 nautical miles (nmi).

Listening Time

Following the transmission of each pulse, the radar switches to receive mode awaiting its return. This break in transmission is appropriately called "listening time." When pulses do not return during their prescribed listening time, the radar assumes no targets were encountered and that the pulse has continued on its outward direction.

Listening time determines a radar's maximum effective range as it, in effect, limits the distance a pulse can travel. If listening time is reduced, pulses can cover less distance and effective range is decreased. Thus, a 50-percent reduction in listening time cuts maximum radar range in half. Only targets within the maximum effective range are detectable.

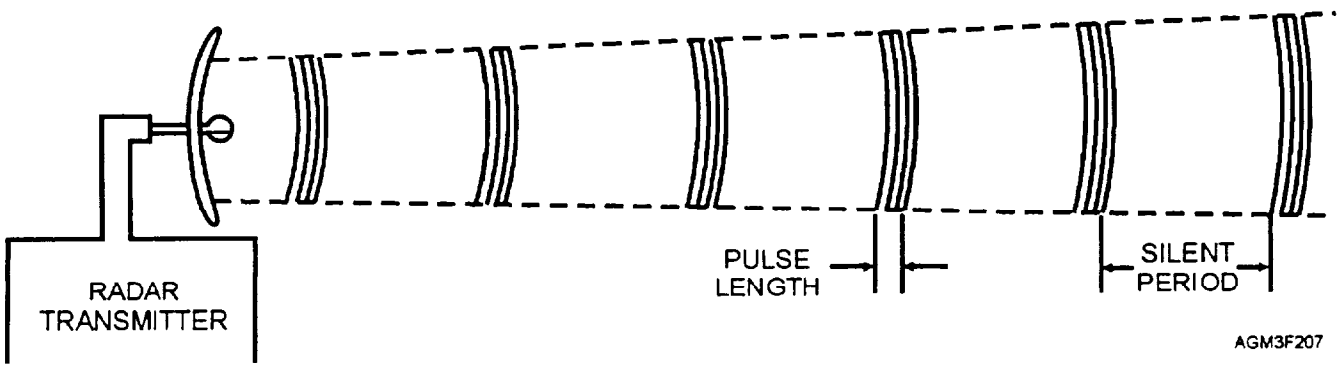


Figure 2-7.—Radar Pulses

Range Ambiguity

As described earlier, the pulse repetition frequency largely determines the maximum range of the radar set. If the period between successive pulses is too short, an echo from a distant target may return after the transmitter has emitted another pulse. This would make it impossible to tell whether the observed pulse is the echo of the pulse just transmitted or the echo of the preceding pulse. This produces a situation referred to as *range ambiguity*. The radar is unable to distinguish between pulses, and derives range information that is ambiguous (unreliable).

In theory, it is best to strike a target with as many pulses of energy as possible during a given scan. Thus, the higher the PRF the better. A high PRF improves resolution and range accuracy by sampling the position of the target more often. Since PRF can limit maximum range, a compromise is reached by selectively increasing the PRF at shorter ranges to obtain the desired accuracy of measurements.

The *maximum unambiguous range (Rmax)* is the longest range to which a transmitted pulse can travel and return to the radar before the next pulse is transmitted. In other words, *Rmax* is the maximum distance radar energy can travel round trip between pulses and still produce reliable information. The relationship between the PRF and Rmax determines the unambiguous range of the radar. The greater the PRF (pulses per second), the shorter the maximum unambiguous range (Rmax) of the radar. The maximum unambiguous range of any pulse radar can be computed with the formula: Rmax = c/(2xPRF), where *c* equals the speed of light (186,000 miles per second). Thus, the maximum unambiguous range of a radar with a PRF of 318 would be 292 miles (254 nmi), 186,000/2 x 318 = 292. The factor of 2 in the formula accounts for the pulse traveling to the target and then back to the radar.

Range Folding

While it's true that only targets within a radar's normal range are detected, there are exceptions. Occasionally, a pulse strikes a target outside of normal range and returns during the next pulse's listening time. This poses a complex problem known as *range folding.* Range folding may cause operators to base crucial decisions on false echoes. The data received from this stray pulse could be misanalyzed and echoes may be plotted where nothing exists. The data may look reliable and the radar may appear to be functioning properly, adding to the deception of normal operation.

Refer to figure 2-8. Assume a pulse was emitted during the radar's previous scan. While it travels beyond normal range and strikes a target, the radar emits a second pulse. Since no targets exist within normal radar range, these pulses will pass each other in flight. The first pulse now returns while the radar is expecting the second pulse (during the listening time of the second pulse). The radar believes that the second pulse has struck a target 124 nmi from the antenna and displays. an echo accordingly (target "X"). The operator is fooled by target "X" and issues a severe weather warning, when in fact, no clouds are present. Target "X" was an illusion, a reflection of a thunderstorm located 372 nmi from the antenna. Fortunately, the WSR-88D is equipped with a range unfolding mechanism that attempts to position all echoes properly.

Pulse Volume

As pulses travel they look like a cone with its point cut off (fig. 2-9). They expand with the beam and increase in volume. The volume of a pulse is the space

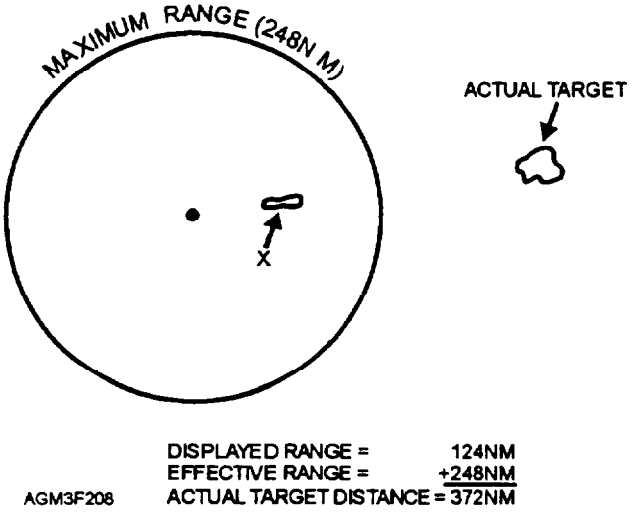


Figure 2-8.—Radar range folding.

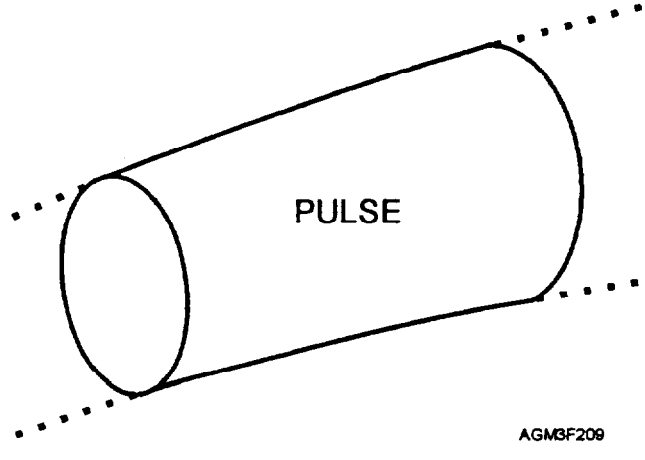


Figure 2-9.—Radar pulse volume. Pulse volume increases with distance from the antenna as the pulse expands in all directions.

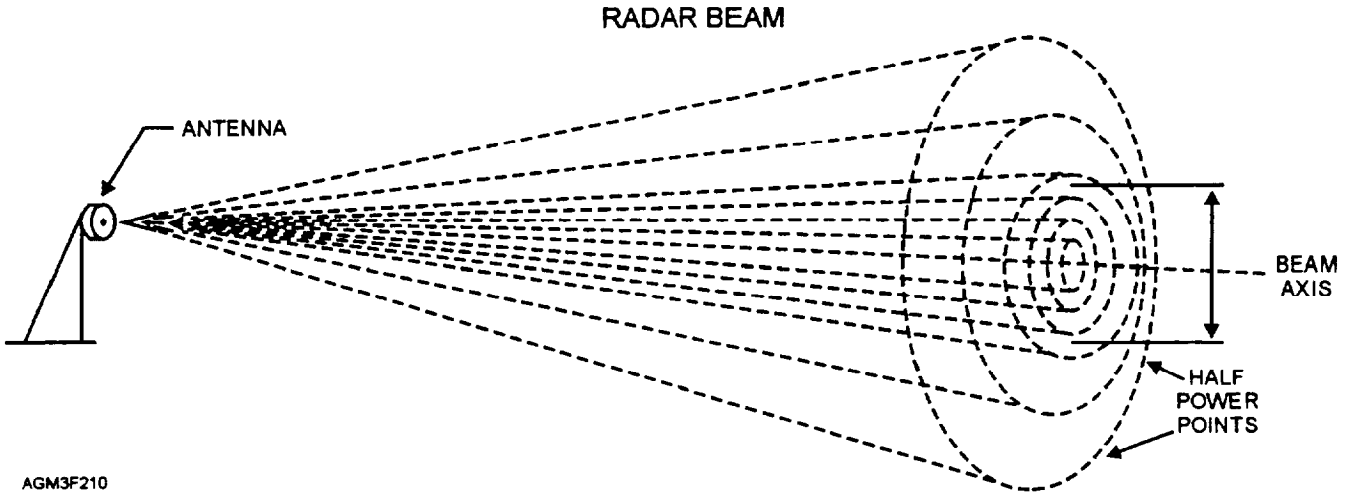


Figure 2-10.—Half-power points and beamwidth.

it occupies along the beam at any point in time. Unlike pulse length, volume does not remain constant. While the amount of power within a pulse is determined by its length and remains constant, power density **decreases** with distance. This occurs because the pulse's fixed amount of energy is spread over a greater area (pulse volume) as the beam broadens. The further a pulse travels, the weaker and less effective it becomes due to increased pulse volume.

RADAR BEAM CHARACTERISTICS

The characteristics of a radar beam refer to **beamwidth, beam broadening,** and the presence of **sidelobes.**

Beamwidth

Since EM energy contains properties similar to light, it can be pointed and controlled much like a flashlight. A suitable antenna can easily focus it into a beam and direct its movement. A radar beam is the path that guides a pulse's travel. Energy emitted into the atmosphere remains concentrated along the beam axis. As you move outward at right angles to this axis, power density gradually decreases. At some point, power density equals one-half of that found at the beam axis. These *half-power points* wrap completely around the beam and define its shape in terms of height and width, or more appropriately, its circumference. The area within these half-power points is defined as the **beam,** and it contains nearly 80 percent of all energy (fig. 2-10). The angular distance between half-powerpoints in a plane passing through the beam centerline is the beamwidth. Beamwidth varies directly with wavelength and inversely with antenna size. Radar systems that produce relatively small beam widths generally provide greater target resolution.

Beam Broadening

As pulses travel away from the antenna, the beam takes on a cone-like appearance and expands in all directions. This expansion or *beam broadening* increases pulse volume, resulting in decreased signal strength (fig. 2-11). Distant targets appear distorted, in fact, they may not be seen at all. Beam broadening also causes "partial beam filling," which implies that distant targets occupy proportionally less of an expanded beam. Thus, the true characteristics of a target may be hidden or altered during display.

Beam broadening reduces azimuthal resolution and produces a form of radar nearsightedness. As the beam diameter increases with distance, closely spaced targets may occupy the beam simultaneously and

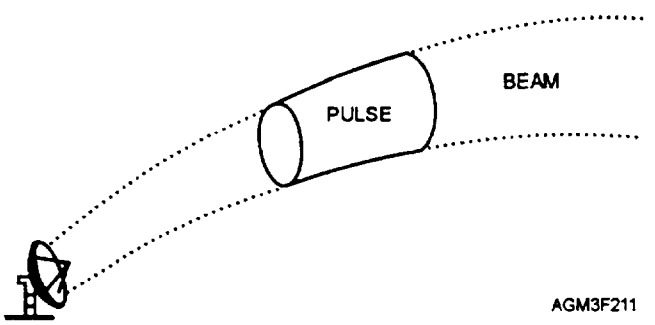


Figure 2-11.—Radar beam broadening.

appear as one echo. In short, multiple targets at a distance are difficult to see correctly.

Sidelobes

In addition to the main beam, antennas produce rays of energy called *sidelobes,* which surround the main beam (primary lobe) like haloes (fig. 2-12). Sidelobes extend outward only a short distance from the radar and contain very low power densities. However, even though they are weak, sidelobes can detect strong non-meteorological targets near the radar and are also disturbed by nearby g-round reflections. This leads to confusion in interpreting close targets because sidelobe targets are displayed along with the main beam targets.

RADAR RESOLUTION

Radar resolution is the radar's ability to display targets correctly. Both azimuthal resolution and range resolution are problems that commonly effect all radars. Recall our earlier discussion about distant objects and their distorted appearance. Resolution affects radar much the same way.

Azimuthal Resolution

Azimuthal resolution is often called bearing or directional resolution. It is a radar's ability to display side-by-side targets correctly. Azimuthal resolution is controlled by beam width as only targets separated by more than one beamwidth can be displayed separately.

As the radar antenna rotates, targets too close together occupy the beam simultaneously. This causes them to be displayed as one wide target, stretched azimuthally (sideways). Since azimuthal resolution depends on beamwidth, which changes with distance, targets near the antenna require less separation than those further out. Near the antenna, a narrower beam allows the radar to recognize tighter gaps and display targets separately. At greater distances, more separation is required. If targets are not separated by the prescribed amount, distortion occurs and resolution suffers. With the WSR-88D, azimuth distortion is approximately 1 mile at a 50-nmi range. Thus, at 250 nmi, two targets must be about 5 miles apart before they will appear as two separate targets.

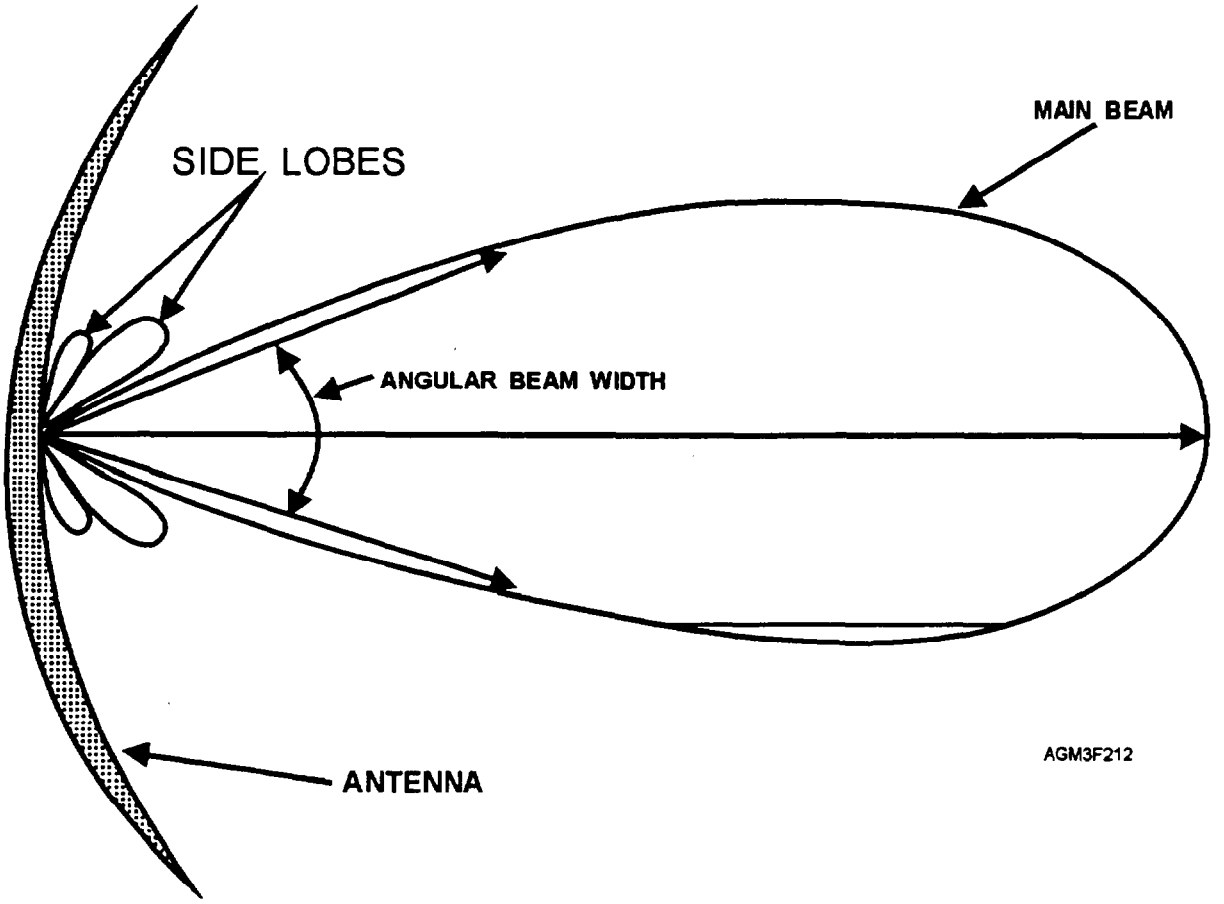


Figure 2-12.—Radar sidelobes.

In figure 2-13, notice that targets located at position "A" are more than one beamwidth apart. The radar therefore displays them correctly, as two separate echoes. Also notice that some degree of stretching is evident, in both echoes, due to partial beam filling. Targets located at position "B" are exactly one beamwidth apart and are displayed as one large echo. As the beam rotates, there is no break in returned energy between targets. As their energy is merged, they appear to occupy the entire beam. Position "C" illustrates poor azimuthal resolution and target stretching caused by partial beam filling.

Range Resolution

Range resolution is the radar's ability to display in-line targets separately. Range resolution affects targets along the beam, oriented behind one another. Targets must be more than one-half pulse length apart or they occupy the pulse together; their returned energy is merged making it impossible for the radar to see their separation. Targets too close together appear as one and are displayed accordingly (stretched along the beam axis). Range resolution is solely a function of pulse length.

Pulse length is unaffected by distance, therefore separation criteria remains constant.

In figure 2-14, a radar pulse is approaching two objects (targets) that are one-half pulse length apart (view A). In view (B), the pulse has hit the first target and some of the energy is reflected back to the radar. In view (C), the pulse has just reached the second target and more energy is reflected back to the radar from the first target. In view (D), the pulse strikes the second target and energy is now reflected back from that target: In view (E), reflected energy from the first target continues to reflect towards the radar along with the second target, which is now one-half pulse length long. Its "front end' is nearly coincident with the first target. From this, we learn why it's impossible for the radar to tell where one pulse ends and another begins. The radar sees one continuous signal. The slightest increase in target separation will overcome this limitation and enable the radar to display both targets correctly.

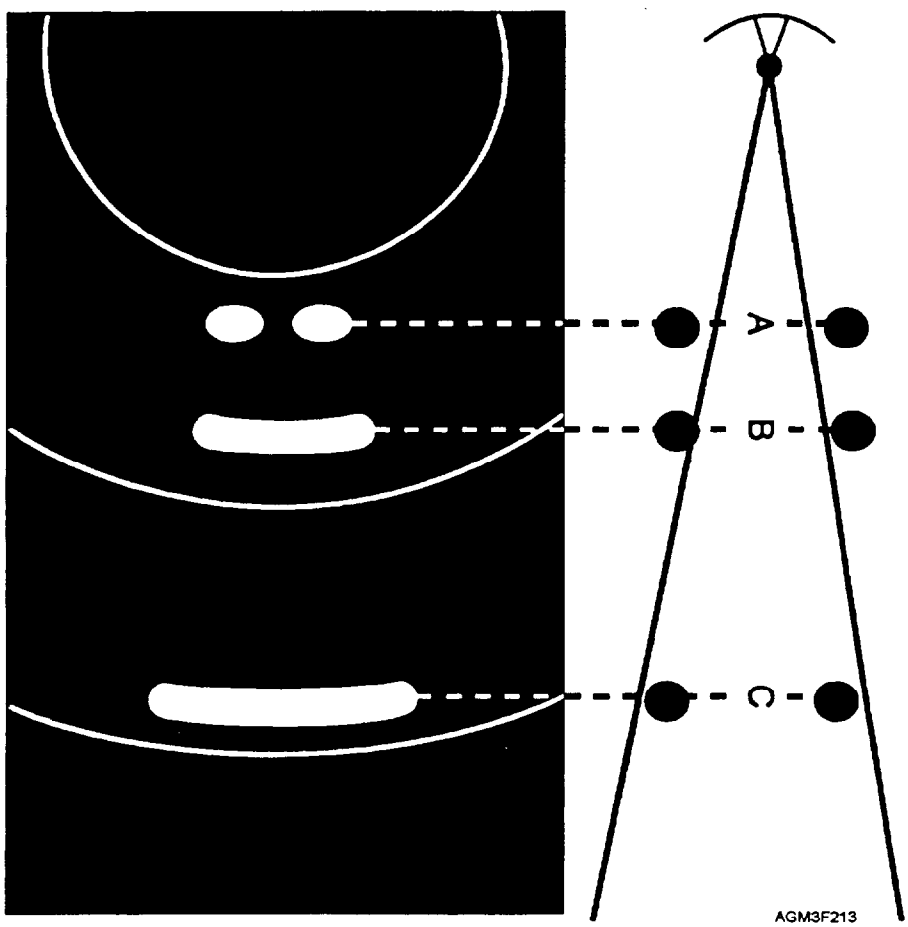


Figure 2-13.—Azimuthal resolution and target stretching.

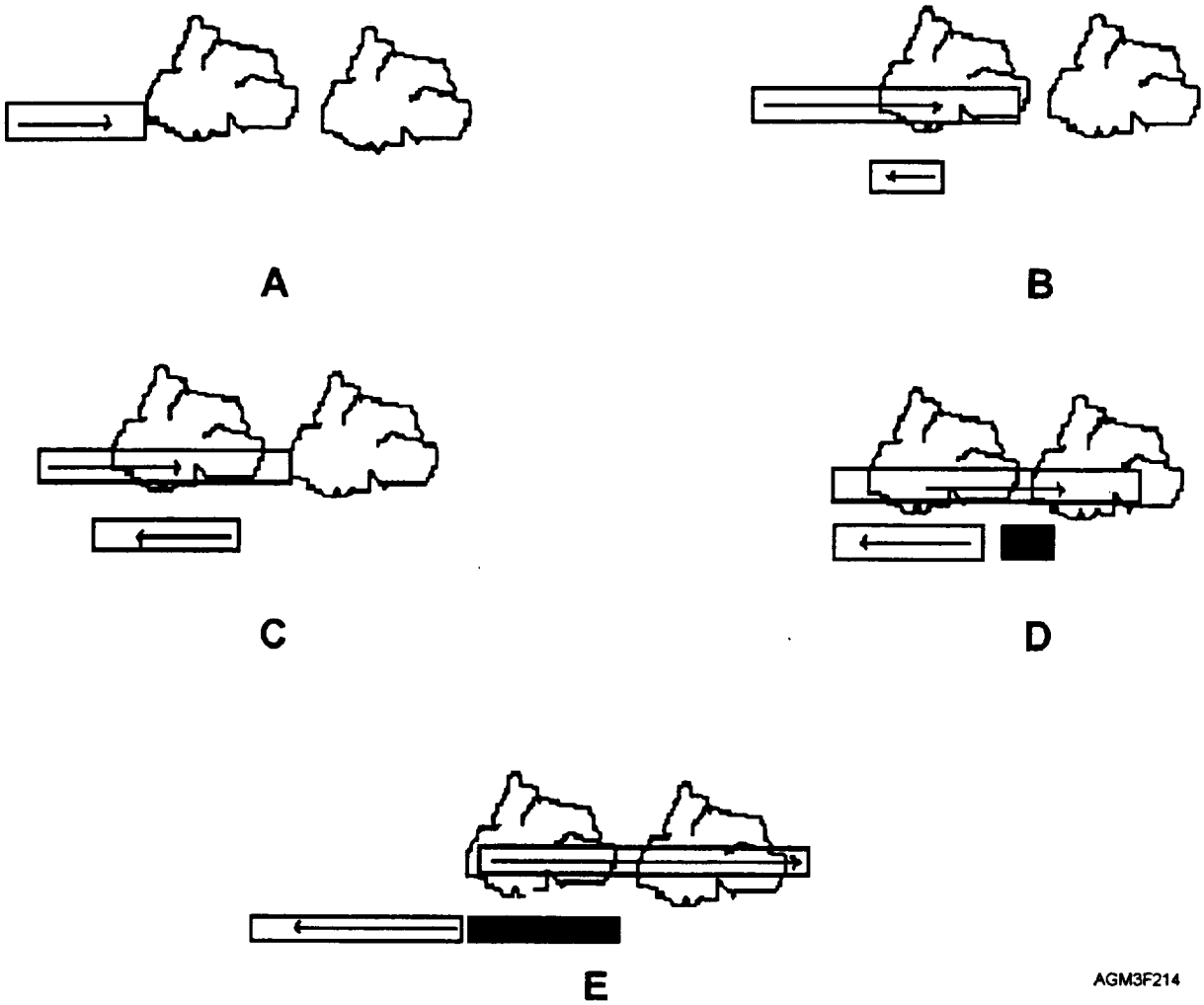


Figure 2-14.—Pulse length versus range resolution.

REVIEW QUESTIONS

Q11. How does pulse length affect the amount of energy returned from each pulse?

Q12. Pulse length is usually measured in what units?

Q13. What is described by the term "resolution"?

Q14. What is a radar's 'pulse repetition frequency"?

Q15. What happens when a radar's PBF is increased?

Q16. What is meant by the term "range ambiguity"?

Q17. If a radar had a pulse repetition frequency (PRF) of 1000, what would be its maximum unambiguous range?

Q18. What causes the phenomena of range folding?

Q19. How does pulse volume affect radar power?

Q20. Which beamwidth would provide better target resolution, a large beamwidth or a *small beamwidth?*

Q21. What is the effect of beam broadening on radar pulses?

Q22. How does the presence of sidelobes affect radar performance?

Q23. What is the main cause of degraded azimuthal resolution?

Q24. What is the main radar characteristic affecting range resolution?

FACTORS AFFECTING RADAR PROPAGATION

LEARNING OBJECTIVES: Define refraction and refractive index. Recognize the effects of refractivity on radar systems. Identify effects of subrefraction, superrefraction, and ducting on radar systems. Define and identify effects of diffraction and ground clutter on radar systems. Identify effects of scattering, absorption, and solar activity on radar systems.

As a radar pulse travels through the atmosphere, various physical actions cause the energy of the pulse to decrease. In this section, we will describe these physical actions and their effect on radar systems.

REFRACTION

A common misconception about a radar beam is that it travels in a straight line, much like that of a laser beam. In reality, the beam (electromagnetic wave) is actually bent due to differences in atmospheric density. These density differences, both vertical and horizontal, affect the speed and direction of electromagnetic waves. In some regions, a wave may speed up, while in other regions it may slow down. When one portion of a wave is slowed and another portion is not, the wave bends in the direction of the **slower** portion of the wave. This bending is known as *refraction.* Refraction in the atmosphere is ultimately caused by variations in temperature, moisture, and pressure, with changes in moisture having the greatest impact.

Refractive Index and Refractivity

In free space, an electromagnetic wave will travel in a straight line because the velocity of the wave is the same everywhere. The ratio of the distance a wave would travel in free space to the distance it actually travels in the earth's atmosphere is called the *refractive index. The* refractive index is symbolized by "n" and a typical value at the earths surface would be 1.000300. Thus, "n" would gradually decrease to 1.000000 as you move upward toward the theoretical interface between the atmosphere and free space. For example, in the time it takes for electromagnetic energy to travel a distance of one wavelength in air at 1000 hPa, 15°C temperature, and 40 percent relative humidity, it could have traveled 1.0003 wavelengths in free space, which makes 1.0003 the refractive index. The normal value of n for the atmosphere near the earths surface varies between 1.000250 and 1.000400.

Since the refractive index produces a somewhat unwieldy number, we use a scaled refractive index called *refractivity.* Refractivity is symbolized by "N" and is a function of pressure, temperature, and vapor pressure (moisture). A result is that atmospheric refractivity near the earth's surface normally varies between 250 and 400 N units (the smaller the N-value, the faster the propagation; the larger the N-value, the slower the propagation). Refractivity values become smaller with decreasing pressure and decreasing moisture, but larger with decreasing temperature. All of these variables usually decrease with increasing altitude. However, the increase in N due to decreasing temperature is not sufficient to offset the decrease in N due to a decrease in moisture and pressure. As a result, refractivity values will normally **decrease** with increasing height.

NOTE: It is sometimes advantageous to compute refractivity in terms of waves traveling in a straight line. This may be approximated by replacing the actual earth's radius (curved earth) with one approximately four-thirds as great ("flat earth"). The refractivity using this orientation is called *modified refractivity* and is expressed in *M units.*

Several software programs such as GFMPL automatically compute N-units and M-units from radiosonde data. N-units can also be computed from a special Skew-T, Log P diagram with a refractivity overprint (DOD-WPC 19-16-2). A refractivity nomogram, such as the one in Appendix II, can also be used.

Refractive Conditions

Under normal atmospheric conditions, when there is a gradual decrease of pressure, temperature, and humidity with height, a radar beam's curvature is slightly less than the earth's curvature. This causes it to gradually climb higher with distance and is called standard or *normal refraction* (fig. 2-15, view A). When there is an unusual or other-than-normal vertical distributions of moisture and/or temperature, nonstandard refraction or *anomalous propagation (AP)* takes place. This causes exaggerated bending of the beam either up or down. There are three categories of anomalous propagation: subrefraction, superrefraction, and ducting.

SUBREFRACTION.—Occasionally, motions in the atmosphere produce a situation where the temperature and humidity distributions create an **increasing** value of N with height. This occurs when density contrast in the atmosphere is weak, such as when water vapor content increases and/or temperature decreases rapidly with height. The beam bends less than normal and climbs excessively skyward. This phenomenon is known as *subrefraction.* Subrefraction causes the radar to overshoot targets that are normally detected (fig. 2-15, view B). Subrefractive conditions are generally rare, and usually occur in desert regions and on the lee sides of mountain ranges.

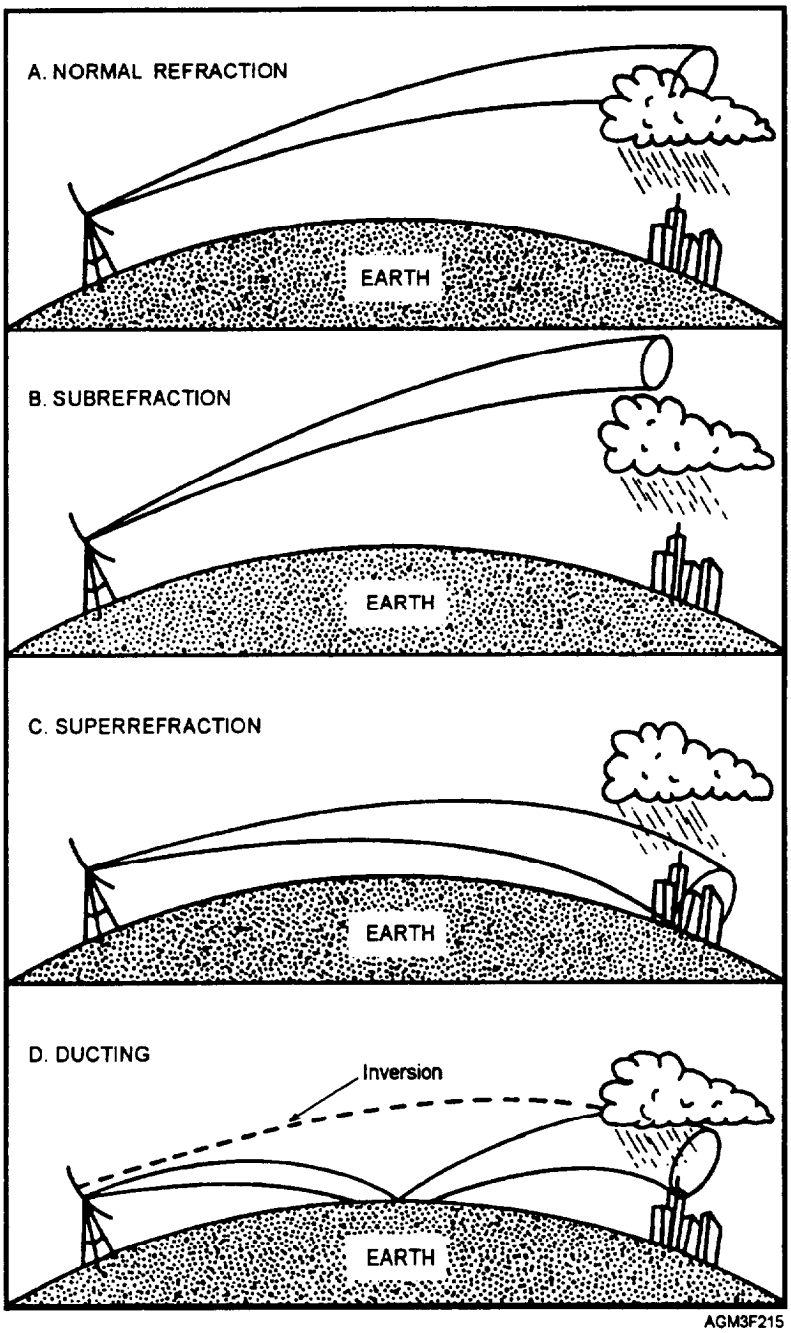


Figure 2-15.—(A) Normal refraction, (B) Subrefraction, (C) Superrefraction, (D) Ducting.

SUPERREFRACTION.— If the atmosphere's temperature increases with height (inversion) and/or the water vapor content decreases rapidly with height, the refractivity **gradient** will decrease from the standard (table 2-1). This situation is known as *superrefraction,* and causes the radar beam to deflect earthward below its normal path (fig. 2-15, view C). Generally, radar ranges are extended when superrefractive conditions exist. However, some targets may appear higher on radar than they would under standard atmospheric conditions.

Table 2-l.—Refractive Conditions as a Function of N-gradient

Refractive Condition	N-gradient
Ducting	≤-48 N/thousand feet ≥-157 N/thousand meters
Superrefractive	-48 to -24 N/kft -157 to -79 N/km
Standard	-24 to 0 N/kft -79 to 0 N/km

Superrefraction occurs under strong inversions, which are typical in subtropical, high-pressure zones.

DUCTING.— In extreme cases, a very rapid decrease in the N-gradient will cause radar waves to become trapped in a layer of the atmosphere and travel abnormally long distances (table 2-l). This phenomenon is known as *ducting* and is a frequent occurrence when strong inversions are present. When ducting occurs, a returning pulse may display low targets from hundreds of miles away-targets that are not normally detected (fig. 2-15, view D). This may cause an effect similar to range folding. False or exaggerated echoes are plotted where no meteorological targets exist. Keep in mind that ducting is also dependent upon the wavelength of the radar. The larger the wavelength, the deeper the layer has to be before ducting can occur.

DIFFRACTION

Electromagnetic waves tend to follow along the curved surface of an object. Diffraction is the process that causes waves traveling in a straight path to bend around an object or obstruction. The direction of propagating energy is changed so that it spreads into a shadow zone, as shown in figure 2-16, view (A). ln the earth-atmosphere system, diffraction occurs where the straight-line distance between the transmitter and receiver is just tangent to the earth's surface as shown figure 2-16, view (B). Generally, the lower the

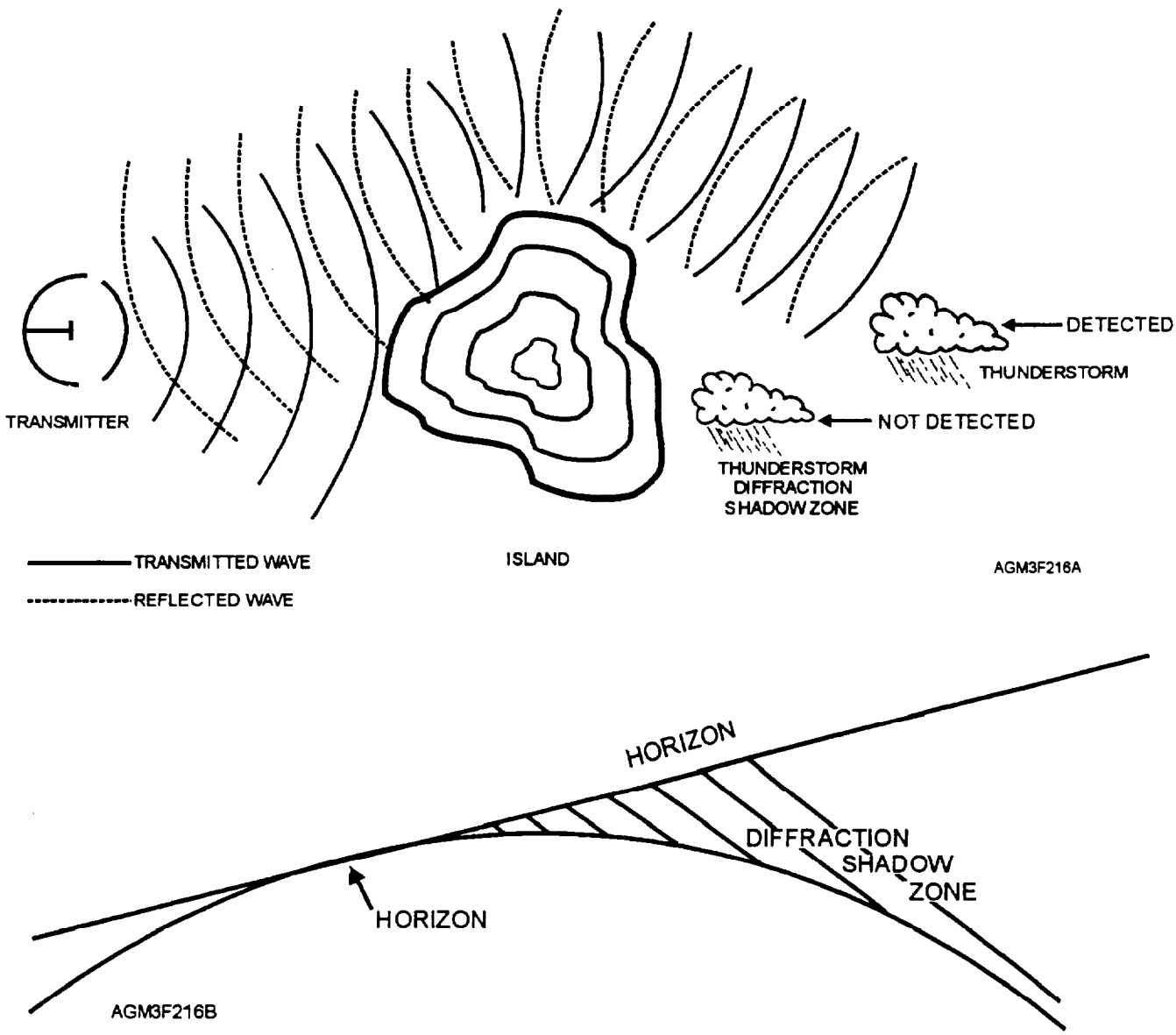


Figure 2-16.—(A) Diffraction of a radar wave front around an obstruction. (B) Radar horizon and diffraction region shadow zone.

frequency (longer wavelength), the more the electromagnetic wave is diffracted. Sidelobes are a direct result of diffraction occurring near the edges of a radar antenna.

GROUND CLUTTER

Another factor affecting radar performance is ground clutter. Ground clutter is an unavoidable form of radar contamination. It occurs when fixed objects, such as buildings, trees, or terrain, obstruct the radar beam and produce non-meteorological echoes. Echoes resulting from ground clutter are usually exaggerated in both size and intensity and may cause radar systems to overestimate precipitation intensity near the radar.

Clutter is normally found close to the antenna where the radar beam is nearest to the ground. Further out, the beam points gently skyward and overshoots most obstacles. Under certain circumstances, however, clutter may exist far away. A tall mountain range would be a good example of this. The key to dealing with ground clutter is operator awareness and experience.

OTHER FACTORS AFFECTING EM ENERGY

As energy travels through space, it interacts with millions of scatterers. This interaction causes a significant amount of energy to be lost or *attenuated.* Attenuation occurs in the form of scattering or absorption, but in either case, it reduces radar performance. The degree of attenuation is dependent on several factors, particularly radar frequency and atmospheric water vapor content.

Scattering

Scattering occurs when energy strikes a target and is deflected in all directions (fig. 2-17). Forward scattering is re-radiation of energy away from the antenna, and all of this energy is permanently lost to the radar. Not all forms of scattering are attenuation. *Backscattering,* for example, occurs when energy is reflected back toward the antenna resulting in a net gain. Larger targets tend to backscatter significantly more energy than smaller ones do, and therefore, result in stronger returns. Without backscattering, no targets would be detected and no echoes would be plotted. The bottom line is that scattering may or may not be attenuation. The type and amount of scattering present determines radar performance.

The degree of scattering is not only dependent on particle size and composition, but also wavelength. Wavelengths used in weather radar are selected to minimize scattering by particles smaller than the radar was designed to detect (i.e. clouds and precipitation).

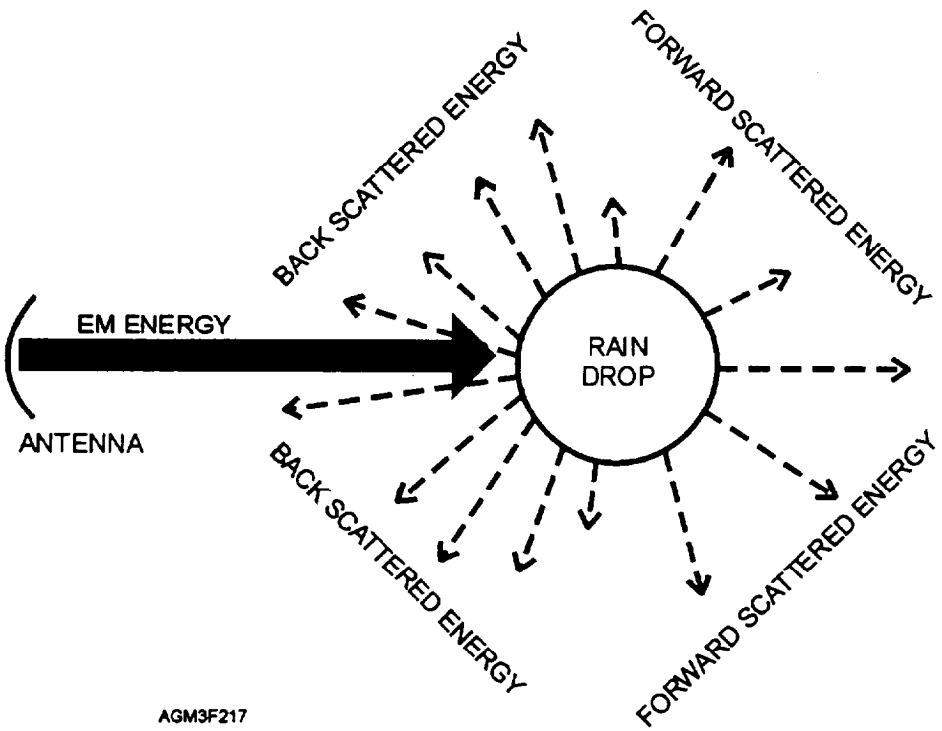


Figure 2-17.—Scattering of radar energy.

Absorption

The atmosphere absorbs some amount of EM energy, mainly by oxygen and water vapor. It becomes trapped within these parcels long enough to become unrecognizable to the radar. Absorption, like any form of attenuation, results in lost power and decreased radar performance. Like scattering, the degree of absorption is dependent on particle size, particle composition, and wavelength. The longer the wavelength, the smaller the attenuation due to absorption.

Solar Effects

Due to the high sensitivity of the WSR-88D, anomalous returns near sunrise or sunset may occur. These false returns are generated because the sun radiates energy in the same region of the electromagnetic spectrum as the WSR-88D. These echoes are recognized by their continuous, narrow "baseball bat" appearance.

REVIEW QUESTIONS

Q25. What is refraction?

Q26. What atmospheric parameter has the greatest impact on refraction and refractivity?

Q27. What normally happens to N-units with increasing altitude?

Q28. If a radar beam is *consistently overshooting targets, which refractive condition might be present ?*

Q29. The phenomenon of ducting is most likely to occur under what atmospheric condition?

Q30. What is the cause of ground clutter?

Q31. What type of scattering is NOT attenuation?

Q32. What are the main absorbers of EM energy in the atmosphere?

PRINCIPLES OF DOPPLER RADAR

LEARNING OBJECTIVES: Define Doppler and Doppler shift. Define phase shift and radial velocity. Recognize the effects of target motion on radial velocity. Define velocity aliasing. Recognize the effects of velocity aliasing on Doppler radar. Compute Nyquist velocity. Identify Doppler dilemma.

So far, we have discussed basic principles of electromagnetic energy common to all radar systems. The following text expands on the theory and principles already discussed and introduces concepts unique to Doppler radar.

Doppler is a means to measure motion. Doppler radars not only detect and measure the power received from a target, they also measure the motion of the target toward or away from the radar. Although Doppler radar enjoyed widespread use for many years, cost made it an impractical tool for weather detection. Only recently has expense been offset by the technological breakthroughs of the Doppler meteorological radar, WSR-88D. This shore-based radar has capabilities that far exceed those of older Doppler systems. These capabilities include a complementary mix of **velocity** detection, increased power and sensitivity, and the integration of high tech computers. This automation provides forecasters with a wealth of information. The WSR-88D not only can detect target motion and velocity, but can also examine internal storm circulations as well as detect atmospheric motions in clear air.

The WSR-88D excels in detecting severe weather events, and more important, increases advance warning time. In addition, the increased sensitivity of the WSR-88D allows various meteorological boundaries to be identified. These boundaries include synoptic fronts, gust fronts, drylines, land and sea breeze fronts, and thunderstorm outflows.

DOPPLER SHIFT

In 1842, the Austrian physicist Johann Christian Doppler first related motion to frequency changes in light and sound. Doppler discovered that the shift in frequency caused by moving sources of sound was directly proportional to the speed of the source. He then developed mathematical formulas to describe this effect called the *Doppler Shift.* While not given much thought, you experience Doppler shifts many times each day. The change in pitch of a passing train whistle and a speeding automobile horn demonstrate its effects. When you hear a train or automobile, you can determine its approximate location and movement.

Doppler radar accomplishes much the same thing, but to a higher degree of accuracy. As a target moves toward a radar, frequency is increased; if the target is moving away from a radar, the frequency is reduced. The radar then compares the received signal with the frequency of the transmitted signal and measures the

frequency shift, giving the motion and speed of the target.

While frequency of electromagnetic energy is modified by moving targets, the change is usually too slight to measure precisely. Therefore, Doppler radar focuses on the **phase** of electromagnetic energy, as this aspect experiences a greater degree of displacement and increases the likelihood of detecting motion. Using phase shifts instead of frequency changes can be compared to viewing an insect under a magnifying glass. Features that might otherwise go unseen take on a new dimension and become observable.

PHASE SHIFT

The phase of a wave is a specific point or benchmark along that wave. A *phase shift* is an observable repositioning of this benchmark between successive transmissions. A pulse Doppler radar, in its simplest form, provides a reference signal by which changes in the frequency phase of successively received pulses may be recognized. The known phase of the transmitted signal allows measurement of the phase of the received signal. The Doppler shift associated with the echo from which the return originated is calculated from the time rate of change of phase.

The phase of a wave, measured in degrees, where 360 degrees equals one wavelength, indicates the current position of the wave relative to a reference position. For example, look at figure 2-18. At time T1 (fig. 2-18, view A), the position of the wave along the vertical line was as shown, while at time T2 (fig. 2-18, view B), the position of the wave along the vertical line was as shown. Notice that the wavelength did not change from T1 to T2. However, the wave's position relative to the vertical line changed 1/4 wavelength, or 90 degrees. This change is the phase shift.

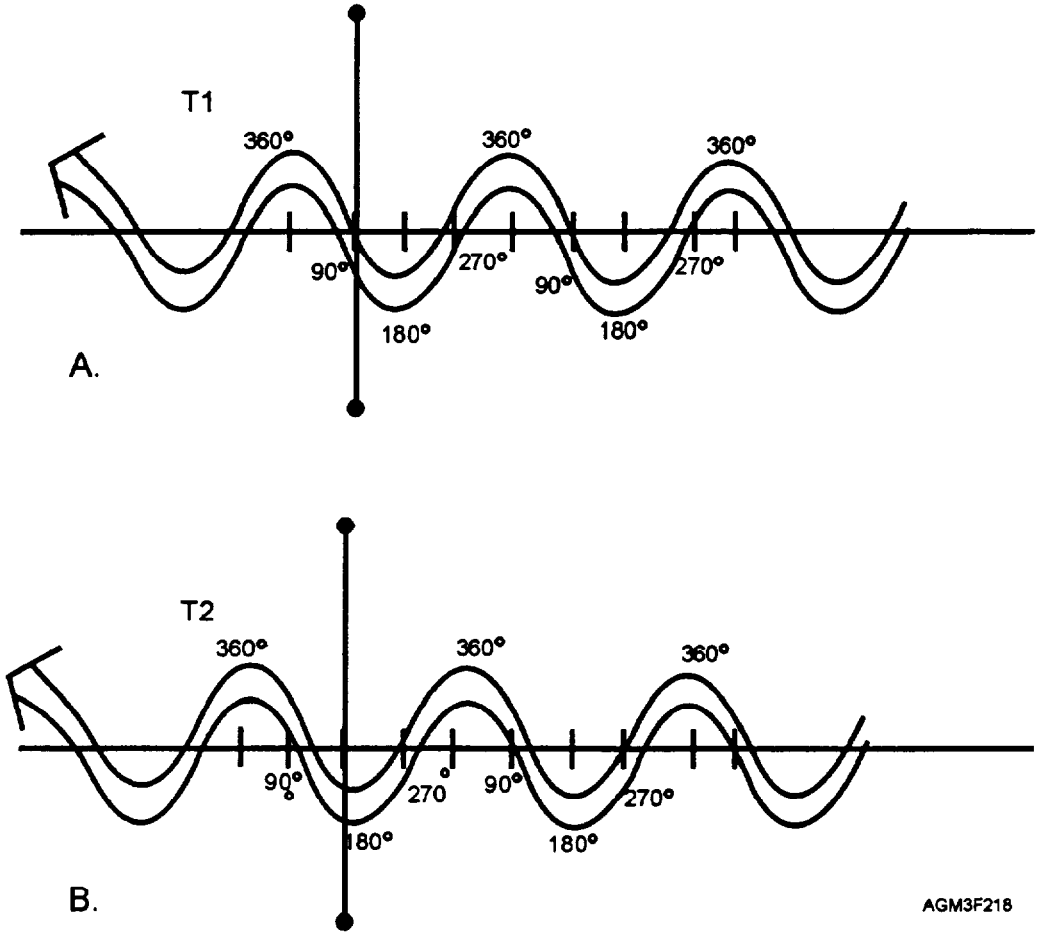


Figure 2-18.—Wavelengths and phase shifts. (A) T-l is wave reference position. (B) T-2 wave's position has changed 90° from reference position (T-l).

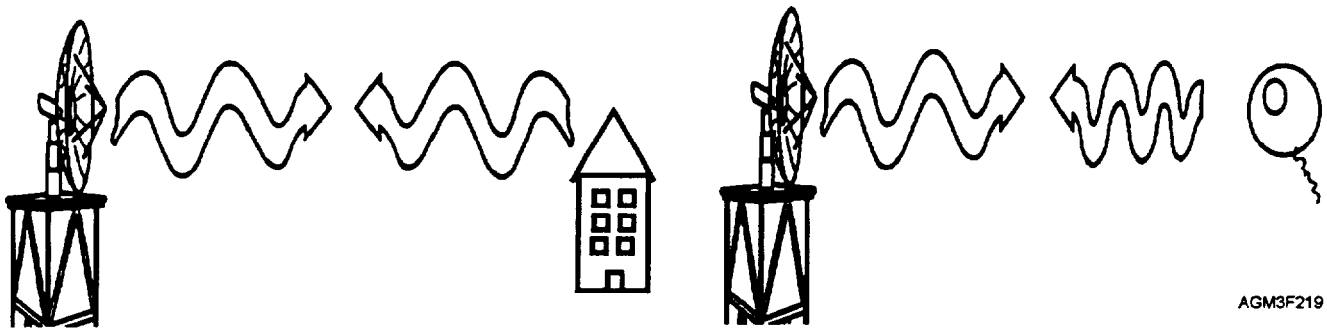


Figure 2-19.—(A) Stationary target causing no visible change in wave characteristics, (B) Moving target displacing energy causing observable phase shifts.

As another example, look at figure 2-19, view (A). Imagine a Doppler radar repeatedly striking a stationary target such as a building. Since the speed at which energy travels is constant, each wave returns in exactly the same phase as those before it. Now look at figure 2-19, view (B). Consider a large balloon moving slowly toward the antenna. Unlike the stationary building, the balloon's motion causes a change in the appearance of each successive wave. If the radar observes these changes (phase shifts) it will realize that motion has occurred and can then convert this information into target **velocity.** Keep in mind that the ability of a Doppler radar to detect phase shifts and compute velocity depends upon the system maintaining a consistent transmitter frequency and phase relationship from one pulse to the next.

RADIAL VELOCITY

We know that Doppler radars can tell whether a target is moving toward or away from the radar. Doppler radars can also measure the velocity of the target toward or away from the antenna. Take a look at figure 2-20. At time T1 a pulse is sent towards a target and it returns at target distance "Y." At time T2, another pulse is sent towards the same target and returns a target distance of "Y+Z." The distance to the target has changed from time Tl to T2, resulting in a phase shift between the two return signals. By measuring the **phase shift,** the **wavelength,** and the **time interval** from T1 to T2, the velocity the target moved toward or away from the radar can be computed.

By convention, motion **towards** a Doppler radar is expressed in **negative** values and green (cool) colors on a display screen. Motion **away** from a Doppler radar is expressed in **positive** values and red (warm) colors.

The WSR-88D's sensitivity enables it to detect extremely weak reflectivities (light drizzle, ice crystals, etc.). This sensitivity allows the radar to determine the wind speed from the size of the phase shift. Even dust or insects can act as scatterers and enable the WSR-88D to determine wind speeds in clear air.

The WSR-88D will not always detect every motion in the atmosphere, nor will it display them with little or no confusion. Since only pulsed energy that returns directly to the antenna can be detected, it stands to reason that phase shifts are only observable when they occur directly along the radar beam (radial).

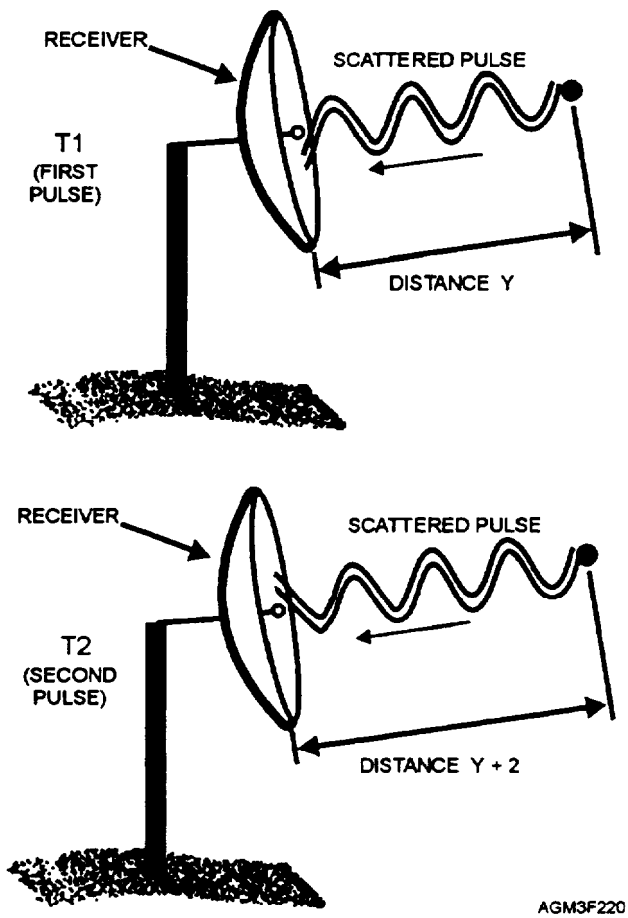


Figure 2-20.—Radial velocity.

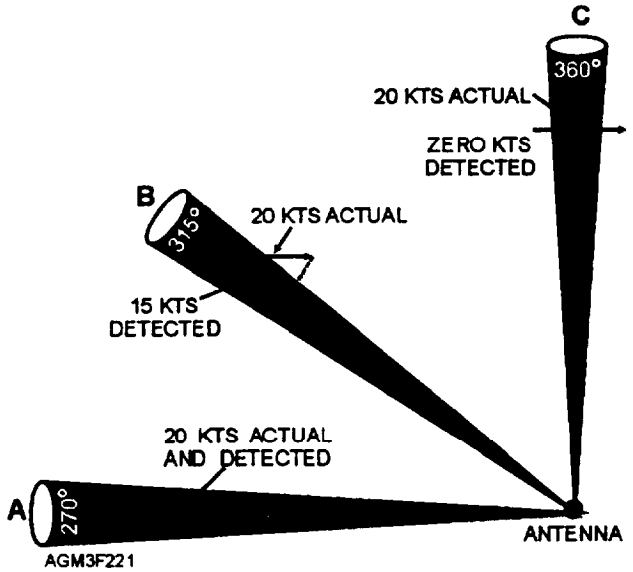


Figure 2-21.—Affects of return component on radial velocity.

Thus, Doppler radars can only measure the component of a target's motion that occurs along the radial axis. This component is called the *radial velocity.*

Motion Parallel Along Radial Axis

If a parcel moves directly toward or away from the antenna, we say its motion is parallel to the radial axis (beam). Truly parallel motions allow the phase shift of each wave to become fully visible to the radar. The result is that displayed velocities reflect the parcel's true speed. In figure 2-21 (component A), the wind is blowing from the west at 20 knots, and the antenna is pointing toward 270°. The WSR-88D views the full component and measures all 20 knots.

Motion Diagonally Across Radial Axis

When a parcel's motion becomes diagonal to the radial axis, only some portion of its phase shift is observed. Since less than maximum motion is realized, an underestimation of target speed is plotted and displayed. The degree of error depends entirely on the parcel's angle and orientation. In figure 2-21 (component B), the wind is still blowing from the west at 20 knots, but the antenna is pointing toward 315°. Only a portion of the wind is blowing directly toward the antenna and the WSR-88D measures only 15 knots.

Motion Perpendicular to Radial Axis

Since the radar antenna rotates in a full circle (360°), the parcel's orientation (to the beam axis) is ever changing. At some point, the parcel's motion becomes perpendicular to the radial and exhibits **zero motion** toward or away from the antenna (fig. 2-21, component C). This does not necessarily mean that the target is stationary. It simply means that the target is remaining at a constant distance from the radar and because of the radar's perpendicular viewing angle, no phase shift is observed. As far as the radar is concerned, the return pulse remains unchanged and no phase shift has occurred. From this information, the parcel is considered stationary. Zero velocity is displayed while the parcel's actual speed goes undetected. In the following text, we will show how the WSR-88D deals with this problem.

VELOCITY ALIASING

Imagine two trains connected back-to-back. Since trains have the unique ability to go full speed in either direction, their orientation poses no problem. Notice the method that trains use to display speed (fig. 2-22).

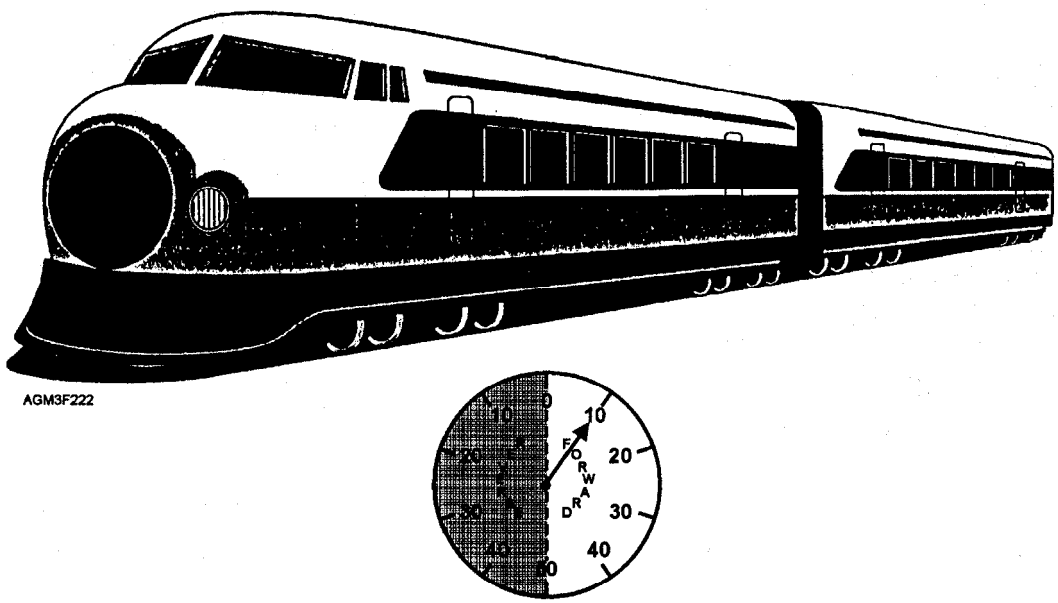


Figure 2-22.—Train speedometer.

Forward speeds are on the right half of the speedometer, while reverse speeds are on the left. Speeds of less than 50 mph are clear-cut (unambiguous), and cause no confusion. However, speeds of 50 mph or more are ambiguous and cause a phenomenon known as velocity aliasing. *Velocity aliasing* is a process that causes a Doppler radar to display untrue velocity values because of the motion of the target.

Consider the following scenario. A train departs the station traveling forward at 40 mph (fig. 2-23, view A). Beyond city limits, its cruising speed is increased another 20 mph (fig. 2-23, view B). Suddenly something is wrong! The speedometer reads 40 mph in reverse. The train did not change direction; it has simply exceeded the limits of its instrument. The train's speed appears aliased as 40 mph *in reverse,* obviously an **ambiguous** velocity.

While radars don't use speedometers, they do measure phase shifts and experience velocity aliasing in much the same way as the train. Consider the 360° of one wavelength as the radar's speedometer. When phase shifts are less than 180° (one-half wavelength), they are clearly detectable. However, shifts of *180° or more* are ambiguous. The radar is unsure if motion is inbound toward the antenna at 60 knots, or outbound at 40 knots.

Look at figure 2-24. In views (A) and (B), the target's motion poses no problem to the radar as both motions produce phase shifts of less than 180° (one-half wavelength), regardless of direction. Illustration (C) depicts a phase shift? of 180°. Here is where the problems begin. Remember, that to unambiguously measure the phase shift, the shift must be less than one-half the wavelength (180°). In this case, we cannot distinguish whether the 180° shift represents motion toward or away from the radar. This measurement is ambiguous. Illustration (D) depicts a phase shift of 270° resulting from energy striking a target that is moving away from the radar. Since a shift of 270° is more than one-half wavelength (180°), it is ambiguous. This 270° shift is seen as a 90° phase shift of motion **toward** the radar. This can result in an aliased velocity being displayed.

While aliased velocities are subject to misinterpretation, the WSR-88D has a unique way of dealing with them. Computer programs are designed to recognize that direction reversal is impossible. They determine that wind speeds are exceeding radar tolerance and calculate the amount of aliasing occurring. All necessary corrections are then applied to the products you receive.

Nyquist Velocity

As just explained, velocity detection is wavelength dependent. As soon as the one-half wavelength limit is passed, the determination of velocity becomes ambiguous. Anytime we speak of wavelength, the same arguments hold for frequency, since they are inversely related. Ultimately, the pulse repetition frequency (PRF) of a radar determines the maximum speed that can be detected without confusion. The maximum unambiguous velocity that can be detected at a given PRF is called the *Nyquist velocity.* Nyquist

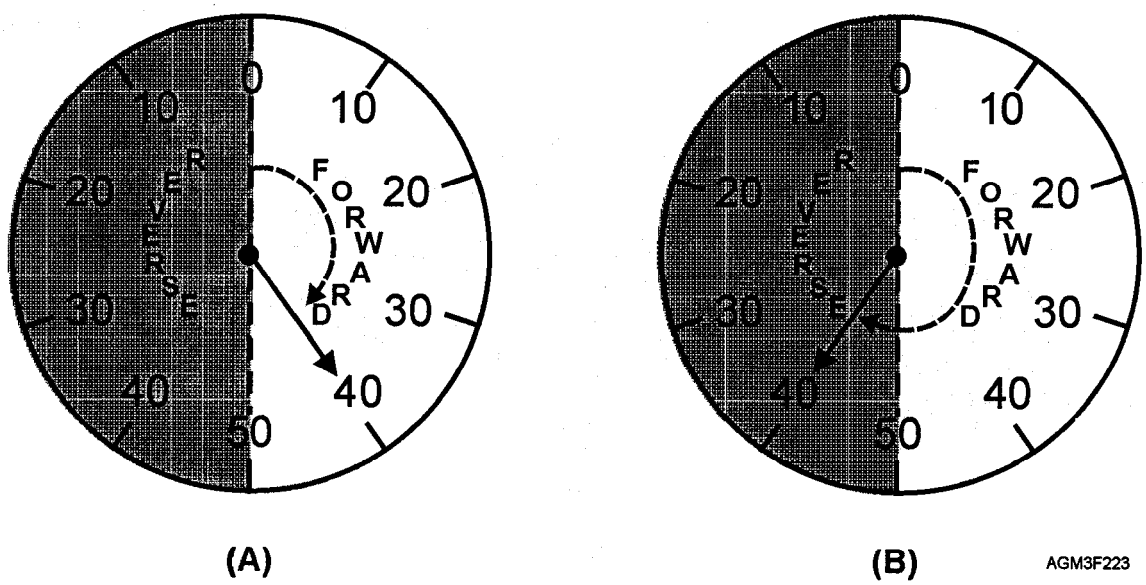


Figure 2-23.—(A) Speedometer showing true velocity. (B) Speedometer showing ambiguous velocity.

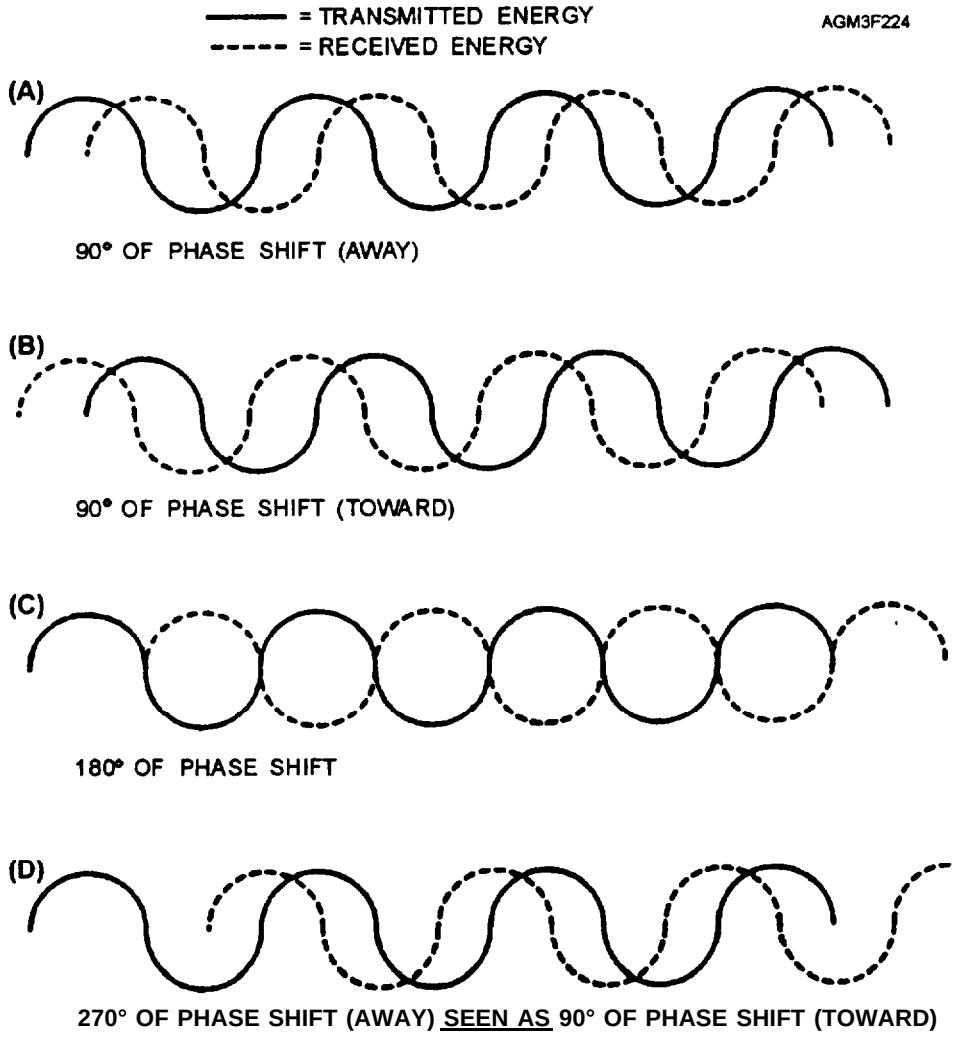


Figure 2-24.—Several phase shifts. (A) 90° of phase shift (away), (B) 90° of phase shift (toward), (C) 180° of phase shift, (D) 270° of phase shift (away) SEEN AS 90° of phase shift (toward).

intervals are those velocities from zero up to and including the Nyquist velocity. The Nyquist co-interval is the entire range of detectable velocities both negative and positive. For example, if the Nyquist velocity is 25 knots, then the Nyquist interval is any velocity from 0-25 knots, and the Nyquist co-interval is -25 through +25 knots.

Since the WSR-88D has a fixed wavelength of 10.7 cm, we can compute the Nyquist velocity (V_{max}) for any given PRF from the following formula: V_{max} = (PRF) x (Wavelength) ÷ 4. For example, a WSR-88D radar operating with a PRF of 1000 would have a Nyquist velocity of 52 knots. This is found by multiplying 1000 by 10.7 and dividing by four (2675 cm/sec). This can then be converted to 26.75 meters per second (100 centimeters in a meter). Multiply this value by 1.94 to convert to knots. From this formula, you can see that higher PRFs yield higher maximum detectable velocities, and that lower PRFs will increase the chances of velocity aliasing.

Doppler Dilemma

We learned earlier that Doppler radar is subject to range folding. This resulted when the radar detected a previous pulse while listening for the most recent pulse. Reducing the pulse repetition frequency (PRF) and allowing for a longer listening time will alleviate the problem of range folding. However, as just discussed, low PRFs may then lead to the problem of velocity aliasing. These two difficulties combine to define what is known as the *Doppler dilemma.* For example, in order for the WSR-88D to detect radial velocities of 200 mph without aliasing, the PRF would have to be increased to about 4,000 pulses per second. However, this would reduce the maximum unambiguous range of the radar to about 20 nmi. To have an unambiguous range of 100 nmi, the PRF would

have to be approximately 810 pulses per second. This would cause the maximum unambiguous velocity to decrease to 45 mph.

The Doppler Dilemma is caused by physical restrictions based on the laws of nature. One of the ways the WSR-88D works around this dilemma is to operate at variable PRFs, collecting reflectivity information at low PRFs and velocity information at high PRFs. The two sets of information collected are compared and processed to estimate true radial velocities and ranges.

Range Versus Height

The WSR-88D samples through 360° at a series of fixed elevation angles. At each elevation angle, the distance outward along the radar beam represents an increase in height above the ground. In other words, the further you move away from the antenna, the higher the beam is off the ground. You must remember that the very center of a product display represents only the height of the radar tower, while the outer edges of the display are thousands of feet above the ground. You can now see how the WSR-88D gives you a pseudo three-dimensional display.

REVIEW QUESTIONS

Q33. Doppler is used to measure what property?

Q34. What are some of the advantages of the WSR-88D over conventional weather radars?

Q35. What happens to a return frequency when a target moves toward a radar?

Q36. What is a "phase shift "?

Q37. The phase of a wave is measured in what units?

Q38. Which three measurements are required to compute radial velocity?

Q39. How is the detected velocity of a target affected as the target moves more perpendicular to a Doppler radar antenna?

Q40. What is "velocity aliasing"?

Q41. What is meant by the term "Nyquist velocity"?

Q42. What would be the Nyquist velocity of a WSR-88D radar operating with a pulse repetition frequency (PRF) of 1100?

Q43. The "Doppler dilemma" is a combination of what two difficulties?

WSR-88D SYSTEM FUNDAMENTALS

LEARNING OBJECTIVES: Identify the major components of the WSR-88D. Identify the purpose of the RDA, RPG, UCP, and PUP. Recognize the various WSR-88D system users and their capabilities. Distinguish between wideband and narrowband communication links. Recognize the basic configuration of the National Weather Radar Network. Identify the various data archive levels. Identify the major volume coverage patterns of the WSR-88D.

The following text provides an overview of the WSR-88D system layout, communication configuration, and data flow. The WSR-88D is much more than just a radar-it is actually a carefully integrated system of basic radar components, sophisticated computer hardware and software, and a unique communications network. Minimum system configuration includes four major components: an RDA (Radar Data Acquisition), an RPG (Radar Product Generator), a UCP (Unit Control Position) and a PUP (Principal User Processor). While these components might be separated by many miles, they remain linked to each other through an intricate communication network (fig. 2-25).

RADAR DATA ACQUISITION (RDA)

The RDA consists of an antenna and all subcomponents necessary to process backscattered (reflected) energy into useful radar information. The RDA is considered to be the radar's eyes and ears because it provides a detailed snapshot of the radar's surrounding environment. It strategically scans thousands of square miles, and controls transmission and receipt of all radar energy. Any accumulation of data is then passed on to the RPG for in-depth analysis.

Radar Moments

Since all atmospheric scatterers provide valuable information, the ability to see them is useful in forecasting, observing, and warning weather customers. Obviously we want to see as many of these scatterers as possible. The RDA is responsible for this detection process. The RDA performs signal processing of Doppler weather radar data and transfers this data based upon three radar moments. A radar moment is a measurement of a scatterer's reflectivity, velocity, and/or spectrum width at a specific period in time.

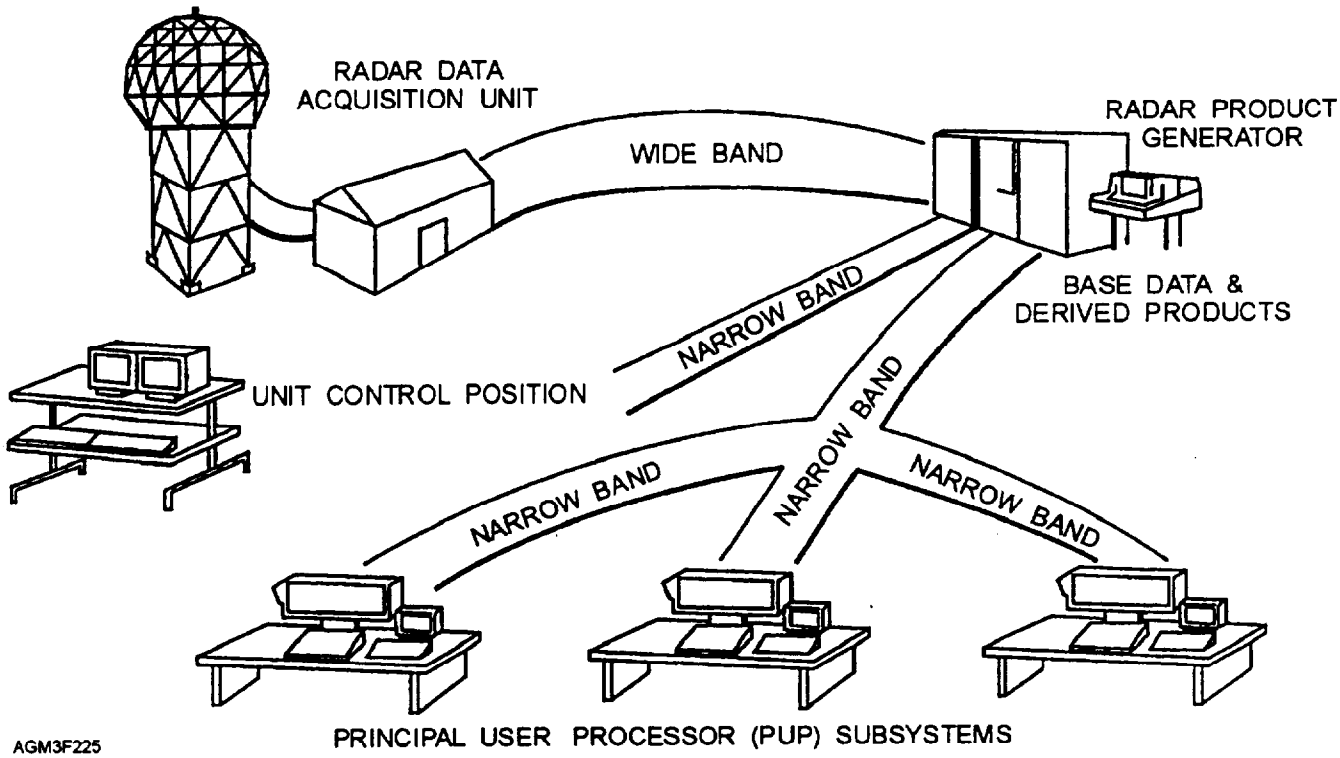


Figure 2-25.—WSR-88D system configuration.

REFLECTIVITY.—Recall, some degree of energy is likely to be returned to the antenna as a result of backscattering, and that size, shape, and composition all contribute to a target's ability to backscatter this energy. Stronger targets have higher levels of reflectivity and return more energy. Thus, stronger targets have higher reflectivity values; that is, higher dBZ levels. For example, large raindrops backscatter many times more power than drizzle and will produce reflectivity levels 5 to 10 dBZ higher. Because of its characteristics, hail tends to have exceptionally high reflectivity values. And, since the WSR-88D displays information in the form of echo intensity levels, a severe thunderstorm with hail will appear much more intense than an area of light rain or drizzle.

VELOCITY.—Velocity is used to determine wind speed, direction, and target motion (perhaps the movement of a thunderstorm cell). The WSR-88D can detect small areas of convergence, divergence, and even circulation. This has proven valuable in alerting whole communities to the onset of strong surface winds and tornadic activity.

SPECTRUM WIDTH.—Spectrum width data is another method of determining atmospheric motion. Spectrum width examines the degree of velocity variance ofparticles (scatterers) in the atmosphere that results from dispersion and mixing. Within a single sample volume of the atmosphere, many particles of varying size, shape, and composition move in different directions and speeds. Because of their differences, each particle moves about independently of the others. Within this single sample volume, the WSR-88D does not sense each individual motion, but rather a combination of all velocities for the overall sample. This combination of different velocities is what spectrum width measures.

Spectrum width data is quite useful in determining atmospheric stability, and is a good indicator of environmental turbulence. By itself, it offers very little guidance. Combined with other products, the user can determine radar performance and reliability of the data being displayed. The concept of evaluating spectrum width data is still relatively new and operational uses are still being developed.

RDA Subcomponents

The RDA consists of all the hardware and software needed to transmit and receive radar energy. It also preprocesses raw data by filtering inconsistencies. The transmitter, receiver, and signal processor are housed together in a small building near the antenna, as

pictured in figure 2-26. These components, together with the antenna, make up the RDA. Only a single RDA exists for each system.

ANTENNA.—The WSR-88D uses a 28-ft dish-shaped antenna to focus radar energy along a concentrated beam. This same antenna is used to receive backscattered energy from targets and atmospheric scatterers.

PEDESTAL.—A cast aluminum structure that secures the antenna to the top of a 98-ft steel tower. The pedestal controls antenna movement with pinpoint accuracy. It rotates the antenna continuously at a maximum speed of 5 revolutions per minute and automatically changes elevation angles in predetermined increments.

RADOME.— A spherical cover that protects the antenna. Made of rigid fiberglass, the radome measures about 39 ft in diameter and resembles a giant golf ball. Its design inhibits ice and snow buildup. Figure 2-27 shows the antenna, pedestal, and radome.

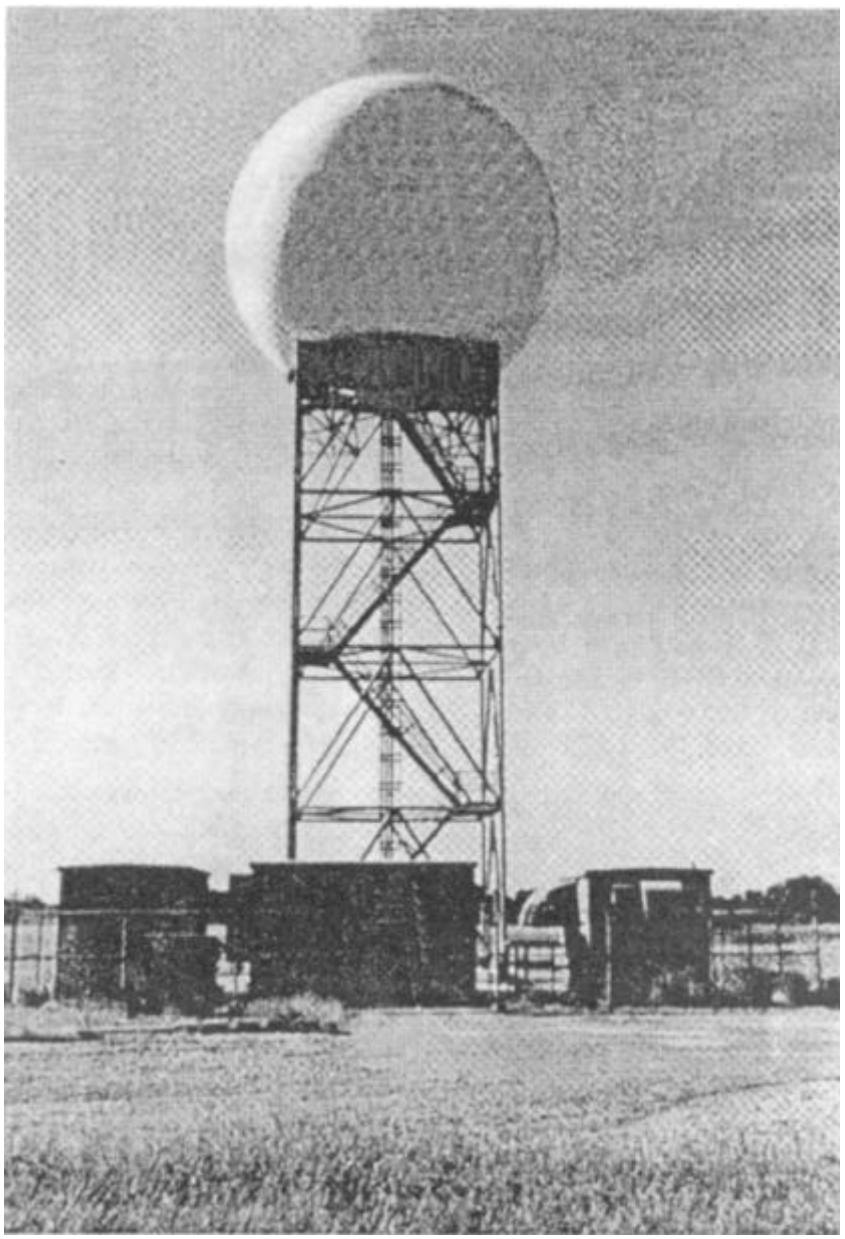


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Figure 2-26.—WSR-88D Radar Data Acquisition (RDA).

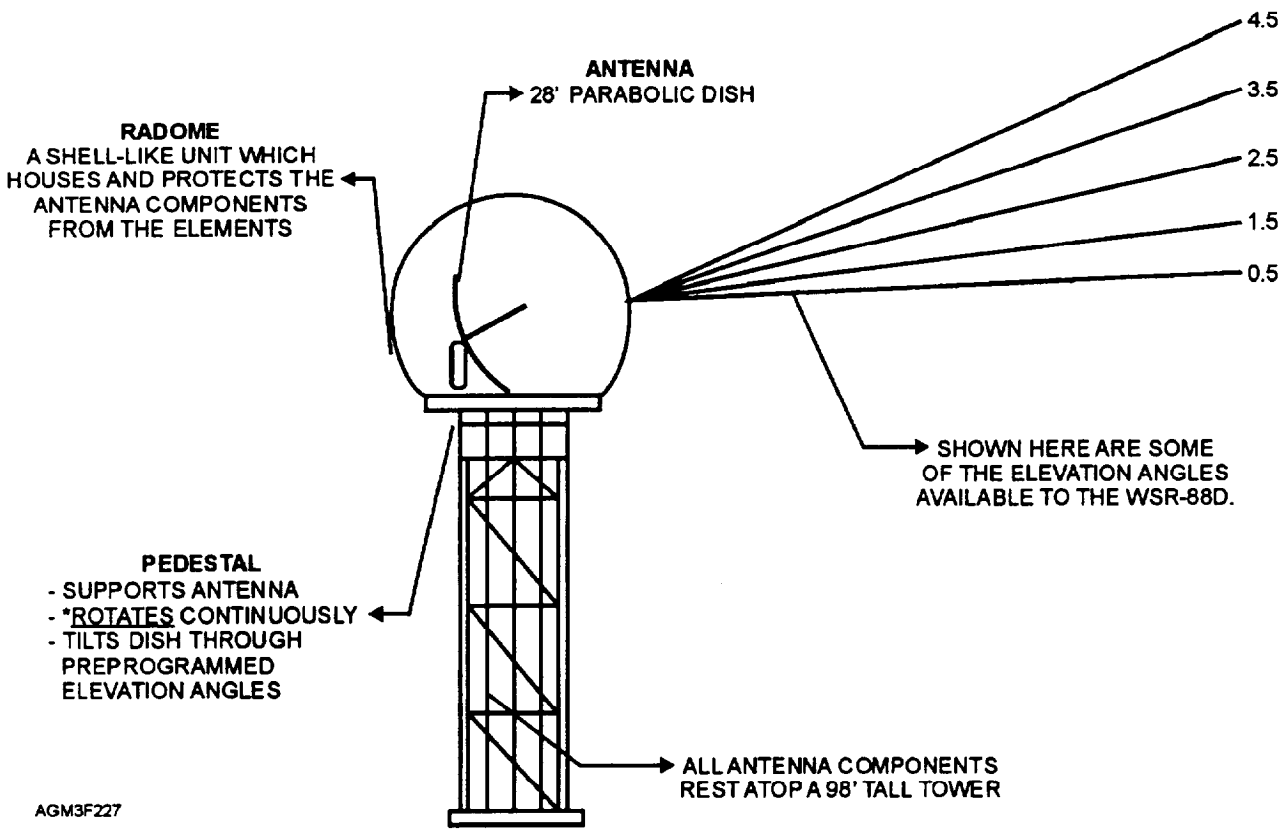

Figure 2-27.—WSR-88D antenna, pedestal, and radome.

TRANSMITTER.—The transmitter is an amplifier that generates high-powered pulses which are then radiated by the antenna. By producing nearly triple the power of earlier radars, the transmitter is the driving force behind the WSR-88D sensitivity. The transmitter has an operating frequency range of 2,700 to 3,000 MHz (2.7 to 3.0 GHz).

RECEIVER.—Backscattered energy generally travels many miles before returning at a fraction of its original strength. This makes it difficult to interpret. Much like a stethoscope helps a doctor hear sounds from deep within your chest, the receiver boosts signal strength of backscattered energy to levels at which the radar can extract crucial target information. Amplified energy is then routed to the signal processor.

SIGNAL PROCESSOR.—The signal processor is the first of four computers within the WSR-88D to encounter radar data. Here, data coming from the receiver is digitized, and contaminants, such as range folding and ground clutter, are reduced or eliminated. This preprocessing converts raw (analog) data into a digitized "base data" format.

RDA Special Processes

The significance of range folding and ground clutter were discussed earlier in this chapter. Two special features of the RDA signal processor include a range **unfolding** process and a ground clutter filtering process.

RANGE UNFOLDING.—The process of cleaning up range folded data must begin by comparing each echo to previous scans. If continuity exists for an echo, the target is considered real and the test is terminated. However, if an echo has mysteriously appeared with no prior history, a secondary test is performed. In such cases, the signal processor compares mystery echoes to energy received from beyond the radar's displayable range. Through pattern matching, it determines the likelihood of each target's true existence, or the probability that such targets are a result of range folded data. If range folding is confirmed, false echoes are removed from products. If the processor is unsure, suspect areas are shaded purple. This purple area is easily recognized and alerts you to the possibility of range folding. When preprocessing is complete, data is transmitted to the RPG.

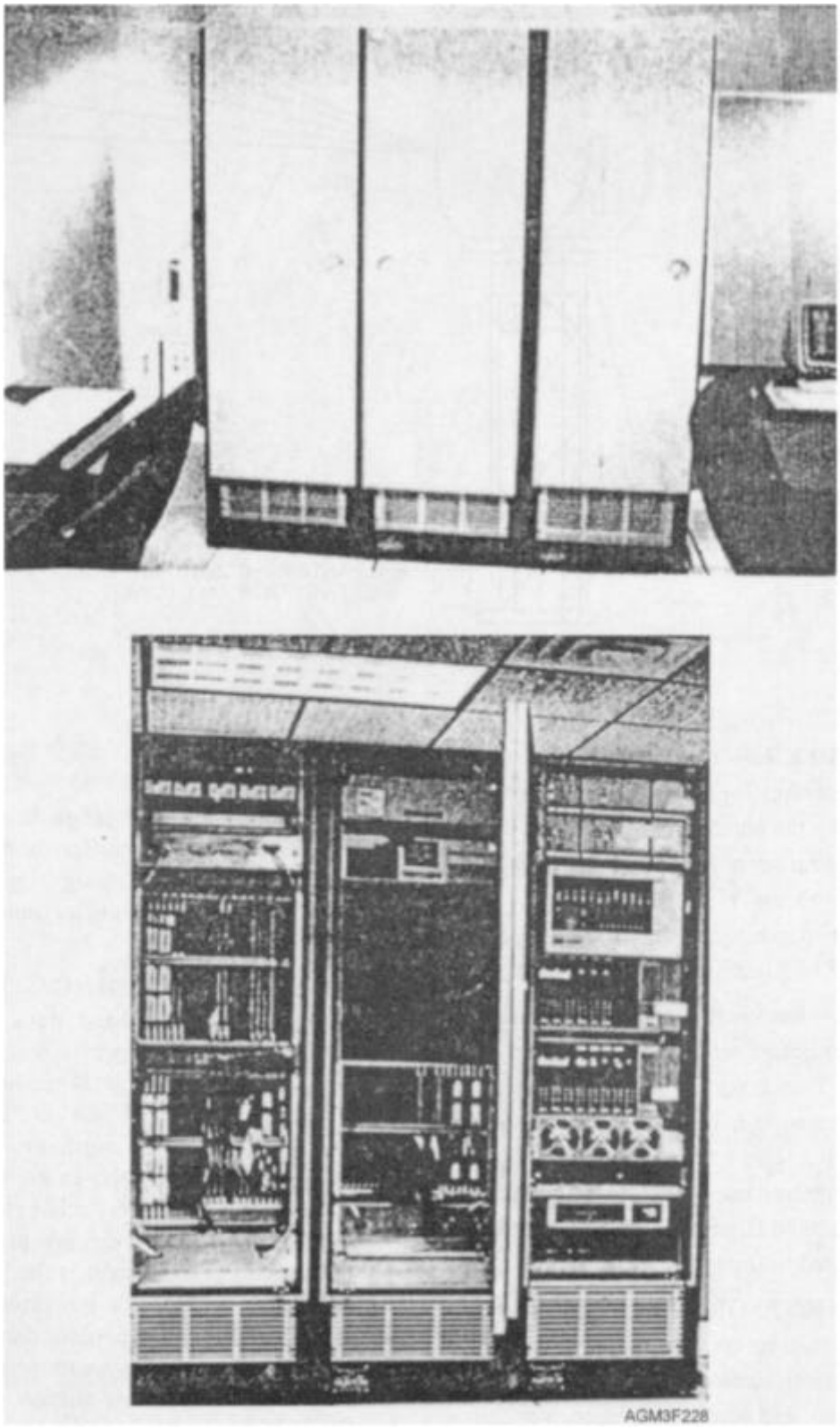

Figure 2-28.—WSR-88D Radar Product Generator (RPG).

GROUND CLUTTER FILTERING.—The process of reducing the effects of ground clutter begins as the data (radar returns received at the RDA) leaves the RDA's signal processor. A ground clutter suppression algorithm is then applied. This algorithm is designed to suppress power (reduce reflectivity) from echoes that return a lot of energy but are not moving (buildings, trees etc.). Two clutter suppression maps are created during this process: one map is used by the RDA to determine which echoes are of a permanent nature (buildings, trees), and a second map that is used by the operator to select areas for specific clutter suppression. Once built, these maps can be referenced by the radar to apply suppression to clutter that has been identified with each new scan of the radar. Obviously, this process increases product reliability.

RADAR PRODUCT GENERATOR (RPG)

The RPG is considered the "brains" of the WSR-88D. It is a bulky mainframe computer, housed in what resembles an oversized wall locker (fig. 2-28). An alphanumeric input terminal allows user interface. The RPG creates all WSR-88D radar products by performing sophisticated analyses of data through a multitude of computer programs called *algorithms.* The RPG provides hundreds of new and unique products every 5 to 10 minutes. Because of the vast quantities available, products themselves are categorized as either base or derived products. **Base** products are near real-time images. They display targets as seen by the radar during its most recent scan. **Derived** products, on the other hand, are specialty products. Derived products evolve from base products that have been modified or enhanced to produce special results. Derived products are often used specifically to examine features that are not easily seen on base products. We will discuss the more important base and derived products later.

Once products are built, the RPG stores and distributes them according to predefined system commands. In some cases the RPG is instructed to generate audible alarms (alerts) when special weather conditions are detected. Once alerted, users may examine conditions more thoroughly by using all available products. Conditions that trigger these alerts are user definable and can be tailored to meet the mission of your base. Strong wind velocities, rotational shear, or intense reflectivity values (from thunderstorms) are among the more popular criteria used to trigger alerts.

The RPG may be located many miles from the RDA, but remains critical to the production process. Without it, NO radar products are available. It is important to mention the links that exist between these components. Considering the volume of data collected, the communications link between the RPG and RDA is crucial. Without it, the system is non-functional. For this reason, the RDA and RPG are connected via a "wideband" communications link, which acts as an information superhighway on which massive volumes of data can flow freely (refer to fig. 2-25). Like the RDA, only a single RPG exists for each WSR-88D system. It supports all users who subscribe for products of that system.

PRINCIPAL USER PROCESSOR (PUP)

Up to this point we've discussed the RDA (which transmits and receives radar energy) and the RPG (which builds products from that energy). Now let's discuss how you will gain access to these products. The PUP is a sophisticated computer workstation that allows human interface with the WSR-88D (fig. 2-29). Here, the observer or forecaster can display or manipulate products freely and perform such functions as zooming (to study tornadic activity), or screen roaming (to examine other weather features). Products can also be time-lapsed. This allows the PUP operator to extrapolate movement of features. Products may be stored locally on the PUP's hard disk, or sent to the printer for a color hard copy.

PUPs are connected to the RPG via a narrow band (ordinary telephone lines). Like other components, PUPs may be geographically separated from the host system (RDA/RPG) by many miles. A minimum of one PUP must exist to constitute a complete system. However, since the WSR-88D is designed to support several users, numerous PUPs can be configured to access a single RPG; the actual number of users varies. Each PUPs distance from their respective RPG depends solely on their geographical location. Common PUP sites include military installations, National Weather Service forecast centers, Federal Aviation Administration airport offices, and the Air Force Weather Agency (AFWA) to name a few. PUP hardware includes the following:

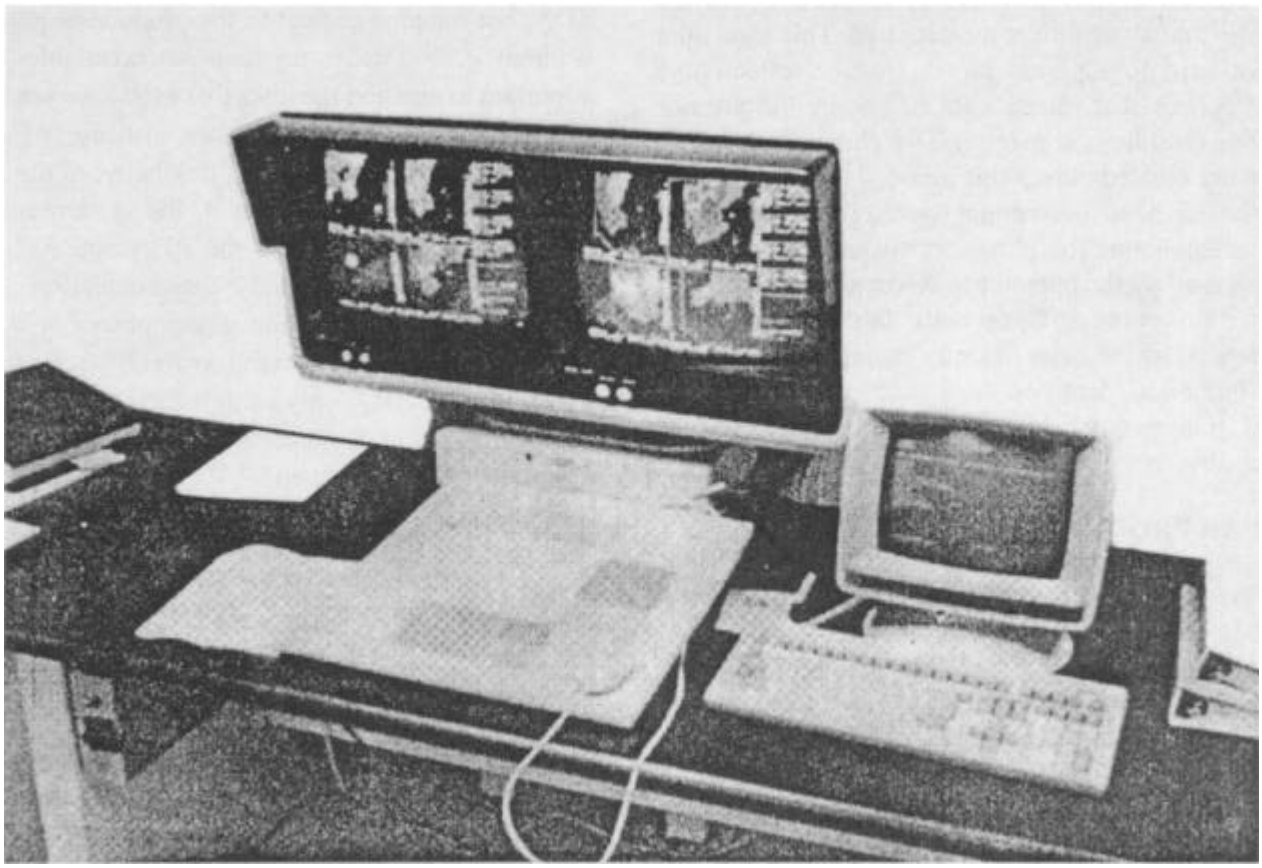

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Figure 2-29.—WSR-88D Principal User Processor (PUP).

• Two 19" color/graphic monitors that are used to display products in full or 1/4 screen mode.

• A graphic tablet and "puck" that are the primary input devices used to make product selections or request actions of the PUP processor. The graphic tablet's surface is flat and is organized as color-coded work areas. The puck is a mouse-like device that acts as a hand-held pointer to invoke desired processor commands.

• A color/graphics printer that provides hard copies on demand.

• A processor that computes or executes user commands (such as zooming, roaming, displaying maps or overlays, and implementing time-lapse loops of products). It also lets you annotate (write, or draw on) products to highlight features such as fronts. The processor also executes special product requests and forwards them to the RPG. The PUP processor is housed in a cabinet much like the RPG but its other components resemble a computer workstation.

• A system console alphanumeric terminal that is usually located in close proximity to the PUP work space. It consists of a monochrome monitor and keyboard. The system console controls the processor by invoking hardware and software commands that affect PUP functions. It also receives alphanumeric products or messages that are not displayed on the graphic monitors.

UNIT CONTROL POSITION (UCP)

The UCP is the fourth major component required to complete a WSR-88D system. Because of its function, the UCP is regarded as the radar's central

nervous system (fig. 2-30). It ensures system integrity and reliability by monitoring and regulating each component's activities. It is used to set all adjustable parameters that determine PRF, antenna position, and all processing thresholds. The UCP is tasked with resolving operational conflicts, such as load control when overload conditions occur. The UCP executes commands via a narrowband link with the RPG (fig. 2-25). It manages both an "application" function and a "system console" function. These functions control hardware and software throughout the entire system.

Application Terminal

The applications terminal manipulates or changes **hardware** performance. It controls RDA and RPG operations including product generation, distribution, and storage. It manages internal communications and allows the isolation of individual components, or the disconnection of any user. It controls all message traffic between individual users and the UCP operator, and may restrict system access. The UCP operator can monitor system status to ensure smooth operation.

System Console Terminal

This function primarily affects **software** performance. It provides user interface to the RPG. Specific operations include start-up and shutdown of application software, executing system diagnostics, and performing maintenance operations.

The UCP normally consists of two monochrome monitors and two keyboards (one for each function). Some UCPs, however, use only a single monitor/keyboard combination that toggles back and fourth between application and system control functions.

SYSTEM USERS

The WSR-88D is uniquely supported by a triagency program that includes the Department of

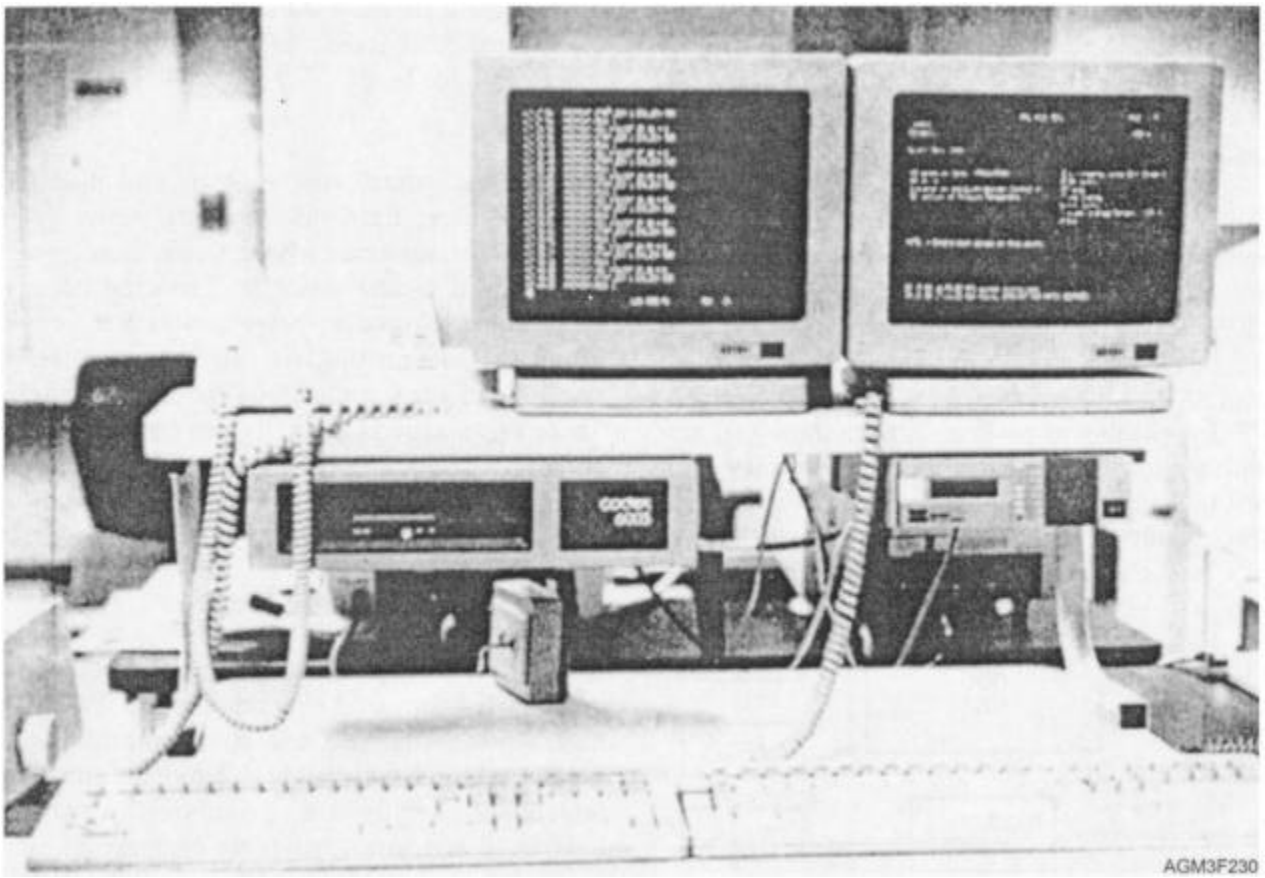

Figure 2-30.—WSR-88D Unit Control Position (UCP).

Commerce (National Weather Service), the Department of Defense (Navy/Marine Corps/Air Force), and the Department of Transportation (Federal Aviation Administration). Day-to-day product interpretation and hardware troubleshooting support for the WSR-88D can be obtained through the Operational Support Facility (OSF) located in Norman, Oklahoma. The OSF maintains a 24-hour hotline to respond to technical problems and questions that may arise while operating any component of the WSR-88D. A Naval Oceanographic Component has been assigned by the Naval Oceanographic Office to act as a liaison representative, and to specifically assist any Navy/Marine Corps activity that has a WSR-88D PUP.

It would be helpful to know the different users of the WSR-88D and how they interface with one another. Let's begin by defining all WSR-88D system users (fig. 2-31).

Principal Users

Principal users of the WSR-88D are the National Weather Service (NWS), the Department of Defense (DOD), the Federal Aviation Administration (FAA), and the subagencies they represent. Principal users can be further classified by their mode of access to the RPG. Every principal user needs a PUP to access the RPG (except PUES).

Associated Principal Users (APUPs)

An associated principal user is the priority customer supported by each system. Most Navy and Marine Corps weather offices are APUP sites. APUPs gain RPG access through a dedicated narrowband link (phone lines) and generally reside within 100 nmi of the host RDA. APUPs may request any product which the RPG is capable of producing, even those that are unavailable to other principal users. They may also request the creation of unique products, even if such requests result in increased RPG workload. While APUPs are connected via dedicated link, they're

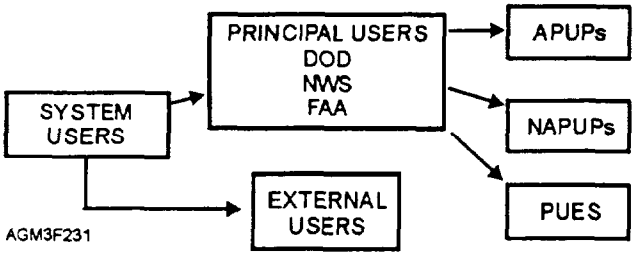

Figure 2-31.—WSR-88D system users.

furnished with the option to dial-in via commercial telephone lines. This enables continued receipt of products in emergency (backup) situations. APUPs exercising this option lose their "associated" status and become "non-associated" user (NAPUP).

Non-associated Principal Users (NAPUPs)

Non-associated principal users are identified as customers that dial-in for access. NAPUPs experience more restrictions than an APUP would. NAPUPs cannot request specialty products, nor can they increase RPG workload in any fashion. In fact, even routine products, maps, and overlays might be unavailable to NAPUPs (restrictions vary from system to system).

Principal Users, External Sources (PUES)

PUES are defined as principal users who access RPGs through nonstandard means. In other words, they do not use a PUP to interface with the RPG. The AFWA is only one of many PUES. The AFWA is a primary user that requires access to hundreds of radars each hour. Its mission is to mass-produce charts for DOD weather stations around the globe. In this example, the customer's own computer meets their needs more efficiently than a PUP would. All PUES are granted RPG access through reserved ports on a space available basis.

External Users

"External users" consist of anyone other than a principal user. External users are normally non-governmental agencies who are authorized access to WSR-88D data and products. These agencies may include news media, private weather services, broadcast meteorologists, airlines, universities, aviation facilities, commercial contractors, and more. These organizations generally pay for dial-in access, and their product selection is severely limited. Specialty products are unavailable to external users and cannot be requested.

SYSTEM COMMUNICATIONS

Good communications is the backbone of any complicated computer network and the WSR-88D is no exception. The WSR-88D communications system consists of two bands that fuse individual components into one efficiently run operation. The two bands (wideband and narrowband) are designed to quickly route data and products between components and users.

Wideband

Wideband is a high-speed link between the RDA and RPG used to transfer massive amounts of data quickly (refer back to fig. 2-25). It also conveys system commands to the RDA (recall, system commands originate at the UCP). Should this crucial link be broken, all antenna functions halt, the processing of real-time data ceases, and communications to and from the RDA are terminated. Wideband link may consist of either hard-wired (direct cabling) to the RPG, or a fiber optic connection. The type of connection used depends largely on distance.

Narrowband

Narrowband consists of a series of dedicated telephone lines that link all remaining components (PUPs) to the RPG (refer back to fig. 2-25). It is primarily used to disseminate products to users and relay UCP commands to the appropriate radar component. Narrowband also carries message traffic between the UCP operator and system users.

If a single narrowband link becomes disabled, only that specific user (PUP) is affected. Since dial-in capability exists, impact to the user is minimal. All access ports on the RPG are designated as either dedicated for APUPs and PUPS or dial-in for part-time users.

NATIONAL WEATHER RADAR NETWORK (NWRN)

The National Weather Radar Network (NWRN) is a composite of WSR-88D sites from around the country. Each site is tasked with the challenge of continuous collection of radar data while ensuring the availability of WSR-88D products to all system users. Currently, this network consists of over one hundred sites providing nearly complete coverage of precipitation and severe weather events throughout the u s .

The NWRN increases the WSR-88D's versatility and establishes greater flexibility for system users. The NWRN allows users to access far away sites, providing live data for aircrew briefings and other types of mission support. Connections are made via commercial phone lines; therefore, access to a remote site defines you as a non-associated user (NAPUP). Once contact is terminated, you can freely return to your host system as an APUP. This capability is a breakthrough for weather briefers as it improves aviation safety. Before its existence, the availability of radar data was extremely limited. Radar charts were often old and unrepresentative of current conditions.

WSR-88D systems have been installed in parts of Alaska and at various sites throughout the Pacific, allowing for even more versatility. For example, you may be stationed stateside and be asked to brief your commanding officer on tropical storm conditions in Guam. As a non-associated user, you can examine live radar information for storm movement, strength, and wind velocity. You can also analyze for tornadic activity, squall lines, and other severe weather signatures-all from the safety and comfort of your own weather office thousands of miles from the event. This is all made possible through the WSR-88D's advanced communications system. Note that any WSR-88D site that is located outside of the conterminous United States (CONUS) is considered a non-network site.

In addition to the WSR-88D PUP workstations, a Supplemental Weather Radar (SWR) is being installed at selected weather stations overseas that do not have access to information provided by the WSR-88D network. The SWR is a commercially developed Doppler radar capable of providing real-time radar surveillance. It consists of a mini antenna and a desktop workstation similar to a WSR-88D PUP. It also produces interperative products similar to the WSR-88D.

ARCHIVING

Archiving is simply the process of preserving data for long-term storage. As information passes from one component to another, archiving may be accomplished in different formats. The WSR-88D uses two types of storage devices, an 8mm magnetic tape and a 5 l/4-inch optical laser disc. The act of archiving occurs at four locations throughout the system. These are identified as Archive Levels I, II, III, and IV. Archive Levels I and II are accomplished at the RDA. This archived data consists of system maintenance information and digital base data from the signal processor. The Archive Level III interface is located at the RPG. At this level, all products produced by the RPG can be saved. The Archive Level IV interface is located at each PUP. Only data available at the PUP may be recorded at Archive Level IV, at the discretion of the user.

VOLUME COVERAGE PATTERNS

Smart scanning strategies are extremely important in optimizing the WSR-88D's detection capability. Unlike older units, the WSR-88D has several different operating modes that can function automatically and continuously. The antenna is also capable of scanning (rotating) at several different elevation angles.

The WSR-88D has a beamwidth of 1° and thus creates 360 "beams" or *radials* of information per elevation angle. The area covered by one complete 360° rotation at one elevation angle is called an elevation scan. The area covered by the radar beam as the antenna rotates through **several** elevation scans (0° through 20°) is known as a volume scan.

The RDA can invoke computer-driven instructions known as *Volume Coverage Patterns* (VCPs). VCPs determine how thoroughly the atmosphere is to be scanned. They dictate the number of areas to scan, the specific elevation angles to examine, and the time allotted for this task. The scanning process is repeated indefinitely, or until a change in VCP is made. Some products may be displayed after just one elevation scan. Thus, each "slice" of the atmosphere is immediately available for examination. Other products are not available until all elevation angles have been scanned for that particular VCP. These products are called *volumetric* products because the entire volume of radar coverage must be scanned before they can be produced.

Two operational modes exist with the WSR-88D: mode A *(precipitation mode)* and mode B *(clear air mode)*. Each mode contains two VCPs designed specifically for that type of environment. Each VCP possesses certain capabilities, as well as limitations.

Mode A (precipitation mode)

Mode "A" is used during periods of precipitation and convective activity. This mode consists of two short pulse (1.57 microsecond) modes, VCP 11 and VCP 21.

VCP 11.—This pattern scans 14 elevations in 5 minutes. It contains fewer data gaps than other VCPs. This increases radar accuracy, making VCP 11 a logical choice for examining nearby storms. VCP 11 provides the most complete coverage of all VCPs, and it is normally used when significant echoes are present or severe weather is occurring or anticipated. Weather events are more accurately depicted on final products. Unfortunately, VCP 11 requires a high degree of data processing, significantly increasing RPG workload.

VCP 21.—This scans nine elevations in 6 minutes. It provides adequate coverage for non-severe events (continuous rain, drizzle). Increased data gaps (less scans) effect performance close to the RDA. However, adequate coverage is provided for distant storms.

Mode B (clear-air mode)

"Clear-air" does NOT imply cloud-free skies, but rather the absence of precipitation from radar. In other words, the criteria for the WSR-88D to use the precipitation mode (VCP's 11 and 21) has not been met over the coverage area of the radar. Mode "B" contains VCPs 31 and 32; both complete five elevations in 10 minutes, both scan slower than mode A, and both contain larger data gaps than VCP 11 or 21. However, in precipitation-free environments, these VCPs are extremely helpful in detecting the early formation of convective precipitation. They are also helpful in detecting air mass discontinuities and monitoring precipitation onset.

VCP 31.—This pattern contains the longest pulse (4.7 microseconds) and the lowest PRF of all VCPs (recall, a longer pulse contains more power and increase sensitivity). VCP 31 scans slowly, to allow sufficient return of energy from clear-air scatterers. The greatest drawback to using VCP 31 is its reduced Doppler capability. While winds and motions are still observed, stronger winds are more likely to aliase when scanning with VCP 31.

VCP 32.—This pattern uses relatively shorter pulses and a higher PRF than VCP 31. It remains sensitive enough to observe most scatterers while increasing Doppler thresholds in clear-air mode. Of course, the weakest features may be lost.

In clear-air mode, the decision to use VCP 31 or 32 (long pulse vs short pulse) is dictated by the meteorological situation and is not always an easy choice to make. For example, on windy days where ample scatterers are present (clouds, moisture, etc.), VCP 32 may be the best choice. Its shorter pulse makes it less likely to aliase velocities. When the atmosphere contains few scatterers, such as on cold, dry days, longer pulses may be required (VCP 31).

The radar makes some decisions by itself. The WSR-88D is designed to operate continuously in "B" mode, but switches automatically to "A" mode whenever precipitation is detected. Precipitation is

classified as the return of reflectivity values greater than or equal to 18.0 dBZ. A return to the "Clear Air Mode" must be manually selected at the UCP.

REVIEW QUESTIONS

Q44. The antenna of the WSR-88D is part of what major system component?

Q45. Which hydrometeor would provide higher dBZ values, hail or drizzle?

Q46. The RDA is capable of reducing or eliminating what type(s) of radar problems?

Q47. Which component of the WSR-88D contains algorithms that create products?

Q48. What is the difference between "base" products and "derived" products?

Q49. Which component of the WSR-88D does the observer or forecaster use to request and obtain products?

Q50. What is the primary input device when operating a PUP workstation?

Q51. Most Navy and Marine Corps stations with Principal User Processor (PUP) workstations are classified as being what type of WSR-88D system user?

Q52. WSR-88D narrowband links are maintained by what mode of communication?

Q53. Data available at the PUP workstation is recorded at which archive level?

Q54. What is meant by the term "volumetric product"?

Q55. Which operational mode and volume coverage pattern should be selected when severe weather is present or expected?

WSR-88D PRODUCTS

LEARNING OBJECTIVES: Identify how WSR-88D products are acquired. Recognize the difference between base data and derived data. Identify the more commonly used base and derived products. Identify the uses and limitations of base and derived products.

In this section, we will explain how products are acquired from the WSR-88D. Next, we discuss in detail the difference between base and derived data. We then examine some of the most commonly used products. Our operational overview of these products will include a simple description, along with a discussion of the purpose, strengths, and limitations of each product.

PRODUCT ACQUISITION

Products from the WSR-88D can be grouped into three general areas of application: precipitation measurement, storm warning, and wind profiling. These products become available to users in one of three ways. They are either specifically identified on a routine product set (RPS) list, solicited as a "one-time request" (OTR), or are automatically generated as an "alert" condition (alert-paired product).

Routine Product Set (RPS)

An RPS list provides an automated way of managing RPG workload. It allows associated users to identify and access routinely required products. Each PUP site tailors its own list according to mission requirements and modifies this list as needs change (via the UCP applications terminal). Each RPS list contains up to 20 products catalogued by name and distinguishing characteristics (i.e., elevation angle, range/resolution, etc.). Products found on the RPS list are generated every volume scan and then distributed to the appropriate user.

One-time Request (OTR)

Products that are not routinely needed are not usually placed on the RPS list. When such products are needed, associated users may obtain them via a one-time request. All one-time requests made by associated users will be honored by the RPG. Products not on the RPS list will be built on demand. With NAPUPs, however, this is not the case. Since non-associatedusers cannot increase the RPG’s workload, new or unusual products are NOT built on demand for them. OTRs made by NAPUPs are only honored for pre-existing products stored in the RPG database.

Alert-paired Product

The WSR-88D is capable of producing alert messages, accompanied by audible alarms. Such alarms are sounded at each PUP site when prescribed conditions occur. Alert criteria are usually based upon severe weather parameters. All alert conditions are user-definable and should be established jointly since they affect each user of an associated RDA. Once criteria are established at the UCP, selected products, known as *alert-paired* products, will be transmitted automatically with each alert. These products aid in severe weather evaluation. Each PUP site receives both the alert message and any alert-paired products. This eliminates the need for one-time requests and allows forecasters to assess the situation rapidly. Alert messages and alert-paired products are given the highest priority by the system.

Significant weather events may be missed under certain circumstances. Thus, alert-paired products reduce the potential of operator oversight resulting from poor product selection. Alert-paired products might mean the difference between ample warning of severe weather or no warning at all. For example, if 50-knot winds will trigger an alert, a base velocity product would most likely confirm the phenomena and assist the forecaster in evaluating the circumstances surrounding that event. This saves time and provides forecasters with the best product for validating the alert occurrence.

BASE PRODUCTS

Recall that the WSR-88D creates two types of products: base and derived. Base products provide a broad overview of the meteorological situation and are the next best thing to viewing electromagnetic energy in its raw state. They graphically illustrate returned energy as reflectivity, velocity, or spectrum width data.

Base Reflectivity (REF) Product

As previously discussed, a radar measures the amount of electromagnetic energy returned to the antenna. The strength of this energy defines a target's intensity. With this in mind, it stands to reason that stronger intensities ofprecipitation from severe storms will contrast sharply from that of surrounding precipitation. In this respect, the WSR-88D truly pays off by transforming backscattered energy into useful, colorful, and interpretable displays.

The practice of displaying reflectivity values from backscattered energy is nothing new. However the process and methods used are becoming more sophisticated. The increased accuracy of the WSR-88D along with the addition of color, makes older radars obsolete. Color-coded targets placed on geographical background maps increase the effectiveness of radar interpretation by providing a clear and informative visual presentation. Operators can quickly compare target strengths and distinguish severe cells at a glance.

Figure 2-32 is an example of the Base Reflectivity (REF) product. Reflectivity data levels are indicated by the color scales found along the product's right margin. With base reflectivity, the data levels refer to target reflectivity intensity (dBZ). Rainfall rates can easily be estimated from REF. Reflectivities from light rain average around 20 to 25 dBZ, while reflectivities from thunderstorms average around 45 to 55 dBZ. Normally, it is difficult to distinguish precipitation type based on reflectivity alone. For example, snow and light drizzle both produce nearly the same reflectivity values. Very high reflectivity values are usually associated with hail. Although base reflectivity has a maximum range of 248 nmi, its best resolution (.54 nmi grid size) is limited to 124 nmi from the RDA. All range folded areas are displayed as purple shading.

Base reflectivity provides a weather snapshot of the entire radar coverage area. Highly reflective storm cores and embedded thunderstorms appear quite nicely in color. These same features were difficult to observe on conventional radarscopes.

Using base reflectivity, an operator can also identify distinct radar *signatures* and correlate targets to their geographical location. Radar signatures are visible patterns commonly associated with certain phenomena. Meteorologists have, over many years, linked a number of weather events with the signatures they produce. Classic radar signatures are often the key to identifying severe weather potential before it occurs. Some of the more important signatures are briefly discussed here.

HOOK ECHO.—The hook is a pendant-shaped echo, resembling the figure *6.* It is produced by precipitation being wrapped around a vortex. Therefore, hooks are typically associated with tornadoes. The hook is not the actual tornado; it is merely an indicator. The right/rear quadrant of a storm (with respect to storm movement) is the best place to monitor development, since tornadoes commonly

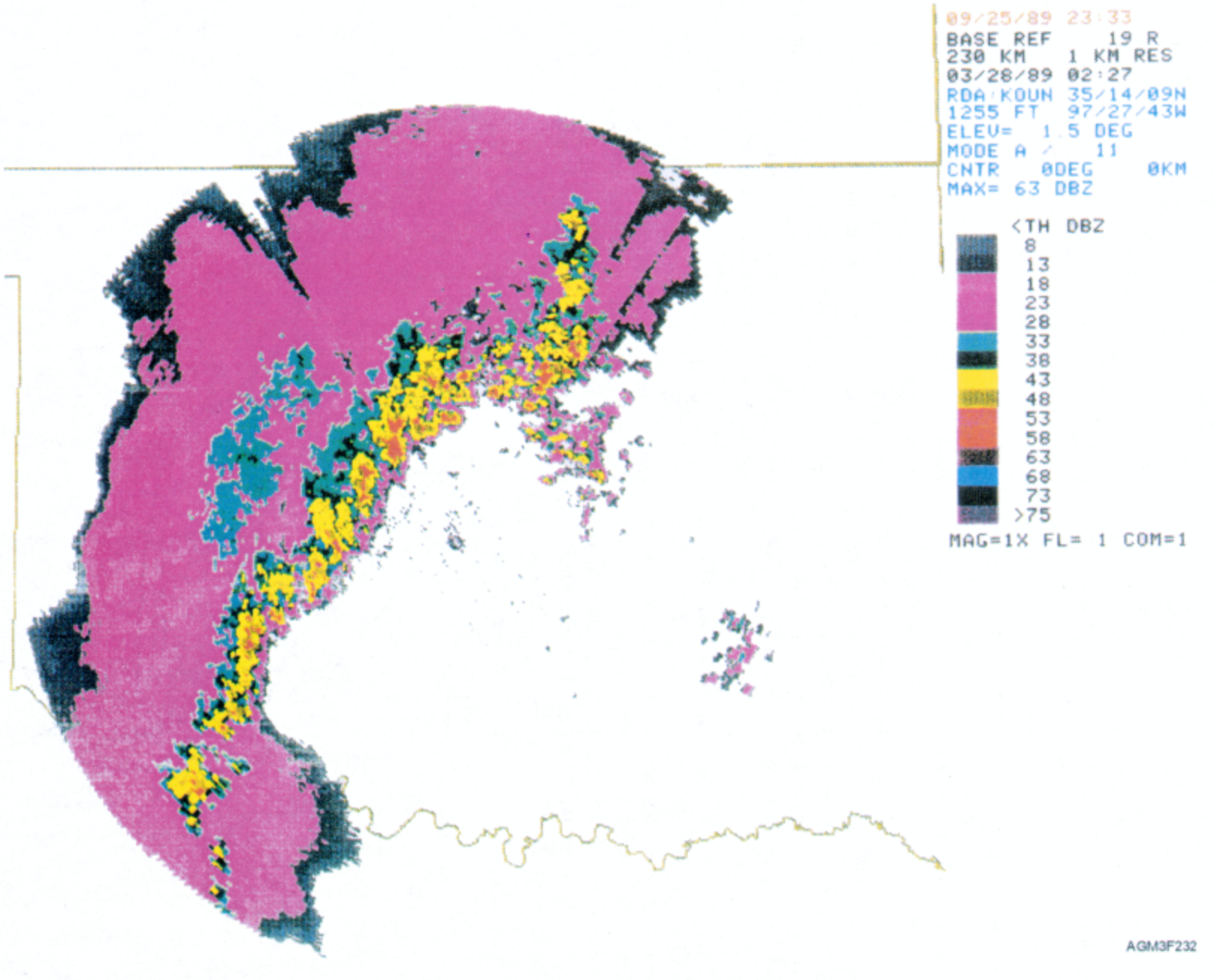

Figure 2-32.—Base Reflectivity product.

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form there. Figure 2-33 exhibits a classic hook signature.

Hook detection is difficult under any circumstances. Hooks are a small, short-lived feature, often obscured by surrounding storm mass. Due to beam broadening, distant hooks might be missed altogether. While the vertical extent of a tornado might exceed 35,000 feet, hooks are most commonly observed on radar at lower elevation angles.

WEAK ECHO REGIONS (WER).—A weak echo region is that portion of a storm exhibiting below normal returns. WERs are normally found at the storm's core. They are formed from the **absence** of water droplets and hail. As intensifying updrafts lift mass to greater heights, they create an area that is void of scatterers (no reflectivity). This area of weak echoes appears hollow within the storm. Notice the weak echo region forming in the lower portions of figure 2-34, view (A).

BOUNDED WEAK ECHO REGION (BWER).—If a WER continues to develop, it will eventually become bounded on all sides by much stronger reflectivities. This occurs as water droplets and hail exit the column at great heights, encircling the updraft core as they fall back toward earth. Bounded weak echo regions (BWERs) generally confirm storm development and imply a transition to severe status (fig. 2-34, view B).

LINE ECHO WAVE PATTERN (LEWP).—A LEWP is simply a line of convective echoes that has become subjected to uneven acceleration. When this occurs, some portion of the line is propelled faster than other portions, causing the line to bend or arch. Because of accelerated movements, severe weather is a regular feature normally occurring ahead of LEWP, at and slightly south of the crest. With this in mind, position "2" in figure 2-35 stands at great risk of these fast-moving storms. The speed of the LEWP itself is a good indicator of its severity.

STRONG REFLECTIVITY GRADIENTS.— From a radar perspective, monitoring rapid changes can best be accomplished by monitoring reflectivity gradients (transition zones). For instance, if the temperature in Chicago is 55°F and the temperature in Biloxi is 65°F, the thermal gradient between these two cities is weak. However, if this same amount of change occurred between New Orleans and Biloxi, the gradient would be much stronger. For radar purposes, reflectivity gradients illustrate the sharpness, or contrast, between a storm and its surroundings. The sharper the gradient, the greater potential for severe weather. Enhanced resolution, color, and digitized displays make reflectivity gradients more observable than ever.

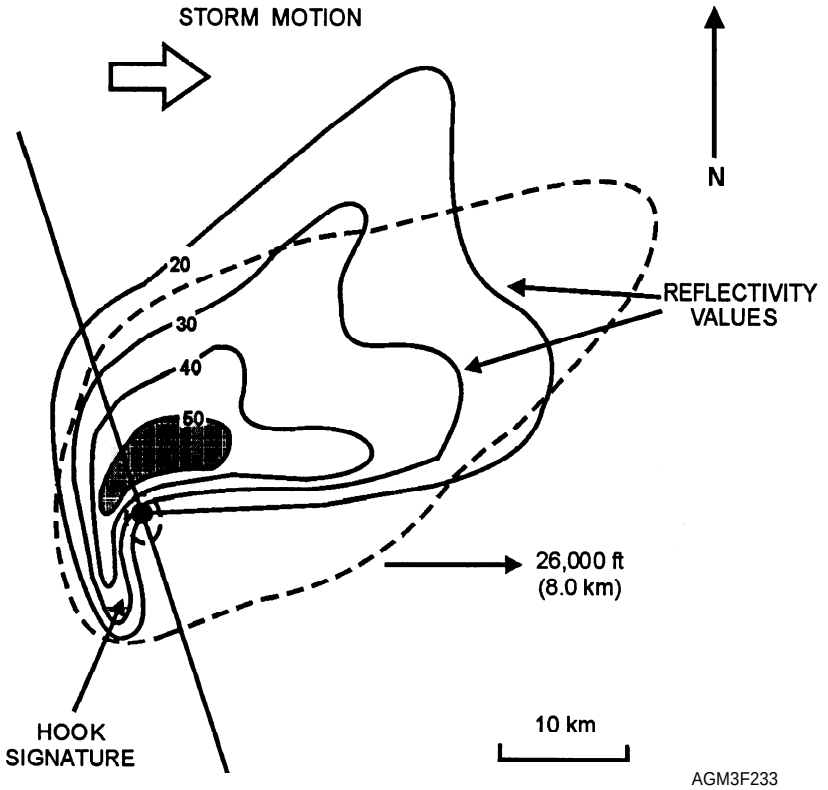

Figure 2-33.—Thunderstorm cell exhibiting a classic hook signature.

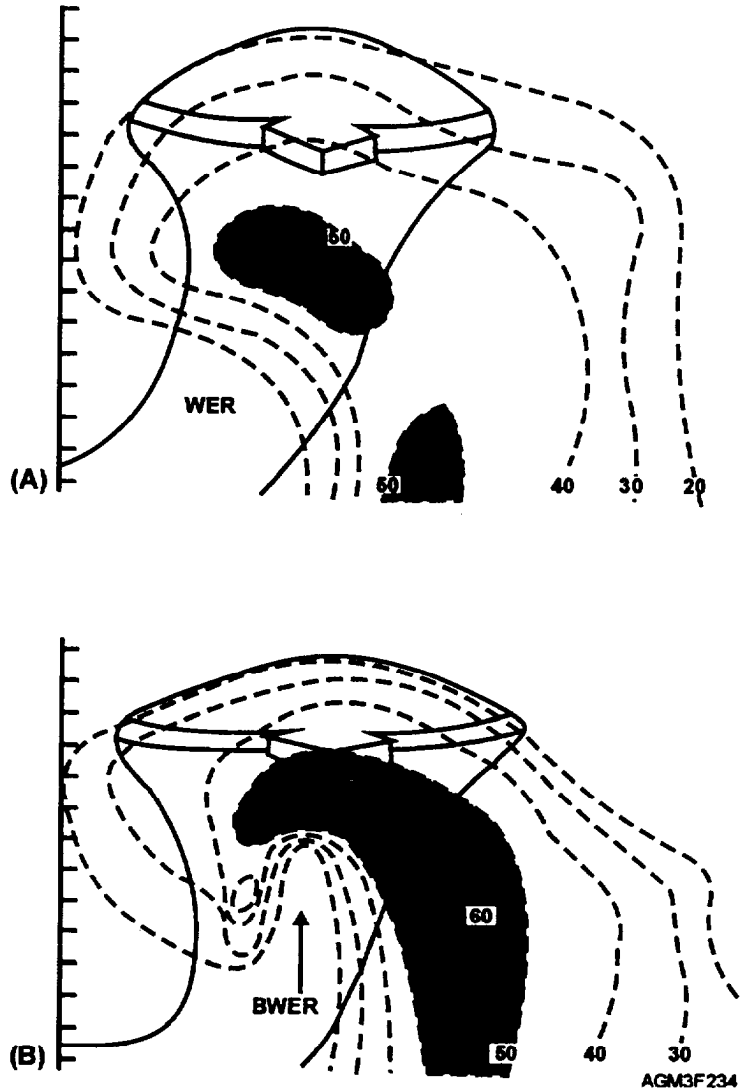

Figure 2-34 .—Thunderstorm cell exhibiting (A) Weak Echo Region (WER), (B) Bounded Weak Echo Region (BWER).

We tend to place a great deal of emphasis on severe weather detection. However, reflectivity serves many other practical uses on a daily basis. For example, we know that precipitation produces a minimum of 18.0 dBZ reflectivity return. Therefore, returns of less than 18.0 dBZ might be attributed to nonprecipitable cloud droplets or other minute scatterers. From this we can estimate cloud heights (bases, tops), the thickness of cloud layers, and the height of the freezing level (altitude at which the air temperature equals 0°C).

In addition, reflectivity can also be used to locate *the melting* level. The melting level is very close to and just below the freezing level; therefore, the melting level is slightly warmer. As frozen particles descend through the melting level, they become lightly coated with water. This makes them highly reflective and produces returns that are stronger than either the frozen particles above or the liquid droplets below. When stratiform clouds are present, the melting level appears as a halo around the RDA (referred to as the bright band).

Keep in mind that the presence of either ground clutter, anomalous propagation, or hail can significantly contaminate reflectivity data and all products built from such data. The Base Reflectivity product may be severely biased, resulting in exaggerated intensities. The product can become deceiving, indicating the presence of strong storms, which may or may not be real. Range folded areas can also cause misinterpretation or obscure valuable data

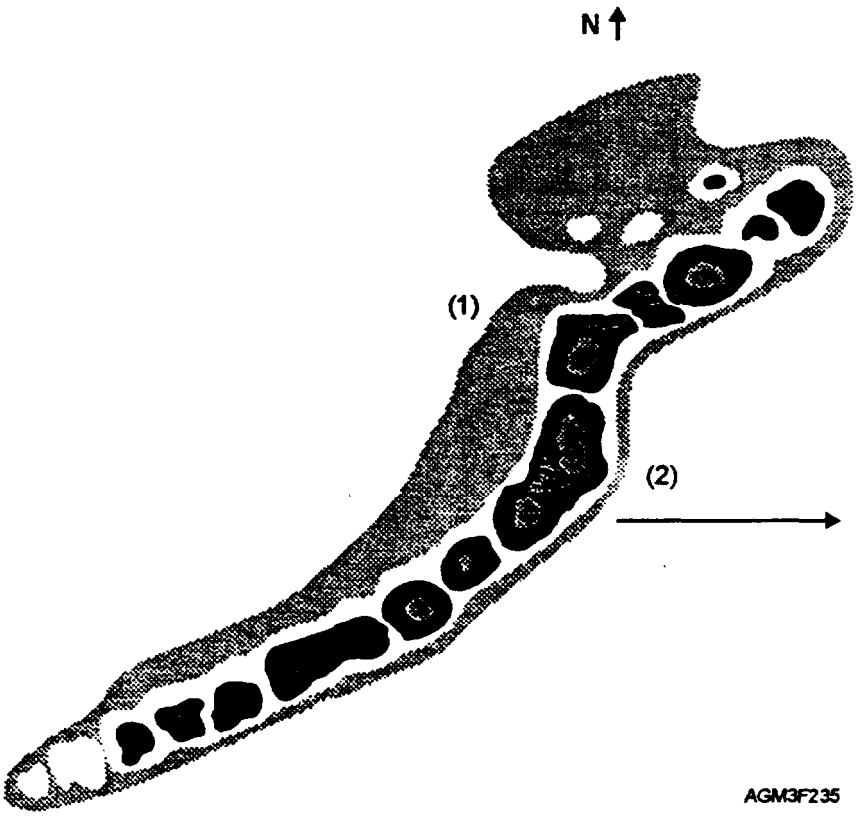

Figure 2-35.—Line Echo Wave Pattern (LEWP). Uneven acceleration causes the line to crest at position (1) and bulge at the point of acceleration, position (2).

beneath the purple shaded areas. And, as with all radar products, successful coverage depends on the availability of scatterers.

Base Velocity (VEL) Product

Doppler radar measures only the radial component of motion (directly toward or away from the antenna). The Base Velocity product (VEL) presents the **mean** radial velocity data. While only two-dimensional data is received, a pseudo 3-D analysis is displayed. Weather features are extracted in both the horizontal and vertical, producing valuable information. As with Base Velocity, a separate product is available for each elevation angle in the current volume coverage pattern (VCP).

The Base Velocity (VEL) product can be used to examine internal storm motions, as well as overall atmospheric flow. In the horizontal, this includes convergence, divergence, rotation, and wind shifts. In the vertical, this product helps locate low and mid-level jet streams and inversion layers. Base Velocity is also useful in locating aviation hazards, such as turbulence and low-level wind shear (LLWS). Any range folded areas, as on base reflectivity, are displayed in purple.

All velocity data from this product must be referenced to a "zero-Doppler" velocity line. The zero-Doppler velocity line depicts points along the radar beam where no Doppler motion is being detected. Remember from our discussion of velocity that this does not mean that no motion is occurring. It simply implies that motion in this region is not being detected by the radar.

Doppler velocities are color-coded while wind directions are not. Cooler colors, such as blues and greens, depict velocities moving toward the antenna (negative values). Conversely, warm colors (red, orange, yellow) are outbound (positive values). Gray colors indicate where the wind component is perpendicular to the radial direction from the radar (zero velocity). Determining the wind direction from Base Velocity data can be difficult and requires practice.

Look at figure 2-36. View (A) shows a vertical profile of uniform wind speed that veers with height. View (B) depicts the same general wind field as it

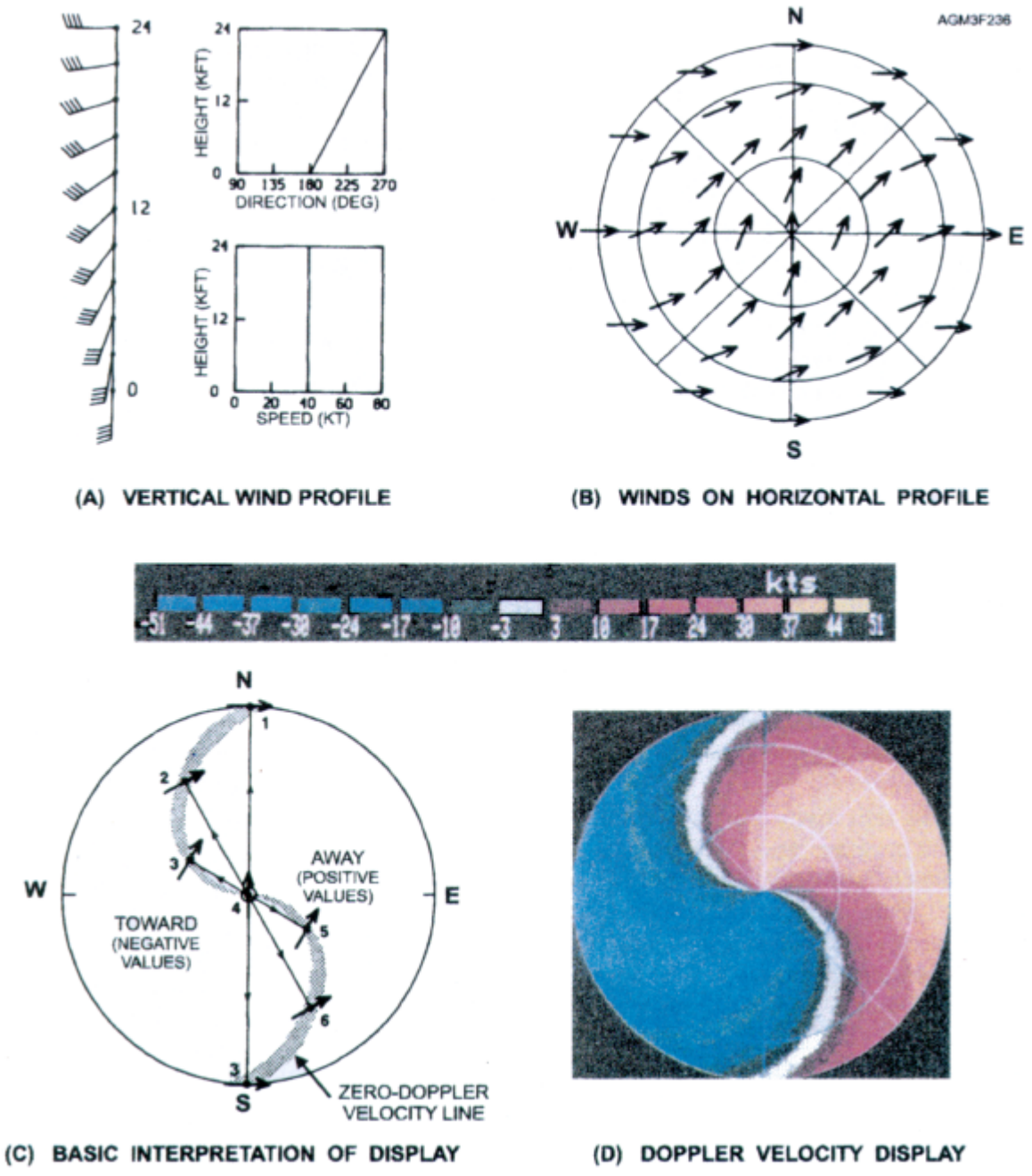

Figure 2-36.—(A) Vertical wind profile, (B) Horizontal wind profile, (C) Basic interpretation of display, (D) Doppler velocity display.

would appear in the horizontal. View (C) is a basic interpretation of wind direction along the zero-Doppler line where the small arrows represent wind vectors. The orientation of the zero-Doppler line in this figure indicates the wind direction is perpendicular to the radar beam at that particular azimuth. For example, along the outer edge of the display, the velocity is zero when the radar beam points to the north (point l), and to the south (point 3). This means that the wind is either blowing from west to east or east to west at the height corresponding to the edge of the display (remember the pseudo 3-D display). Since Doppler velocities are negative along the western side of the display and positive along the eastern side, the wind must be

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blowing from west to east at the height of the display. At point 2, the zero line is oriented east to west. In this instance, inbound velocities are to the south so the wind direction must be 180° near the surface.

Figure (D) is an example of the WSR-88D velocity display. As you can see, areas of red and orange indicate flow away from the radar, while areas of green and blue indicate flow toward the radar. The colors can then be compared to the color scale above to determine wind speed.

Again, successful coverage from this product depends on the size and amount of scatterers available. When ground clutter or anomalous propagation contaminate the radar beam, all velocities will be biased toward zero. When range folding occurs, purple shading might obscure valuable data, causing you to miss significant features. Keep in mind that all velocities are relative to the **RDA,** not the PUP.

DERIVED PRODUCTS

Derived products are enhanced renditions of base products that provide observers and forecasters with a unique perspective of radar information. In the following text, we will discuss some of the more commonly used derived products.

Composite Reflectivity (CR) Product

Recall that base reflectivity provides a "birds eye" view of the radar coverage area. While this is very useful, base products provide data from only a single elevation angle. Thus, only a slice of the overall atmosphere is presented, and valuable information above or below the radar beam may be overlooked. To sample the entire volume scan, radar operators must view each slice individually. This time-consuming process is impractical for the operational user. The WSR-88D offers Composite Reflectivity (CR) as a partial solution.

The CR product contains information found in base reflectivity. However, one very important difference exists:

composite reflectivity operates on a summation principle. That is, the algorithm first compiles data from all elevations (volumetric), and then produces a product which displays only the **strongest** returns for all regions of the radar coverage area. In building the CR product, the algorithm considers only intensity as its criteria. Size, shape, characteristic, and altitude are not factored.

The CR offers a "sneak-peek" advantage over base reflectivity, but should never replace the use of other reflectivity products. When using CR, operators are less likely to miss significant targets since only reflectivity maximas are displayed. The major downside of this product is its loss of target heights. This limitation poses serious problems since echo heights relate closely to storm development. Without height data, targets become deceiving. This product is normally accompanied by an attribute table that ranks storms according to severity and includes forecast movement and the likelihood of each storm to produce a variety of conditions (hail, mesocyclones, tornadoes, etc.).

Keep in mind that values displayed for a given location could have come from any altitude or elevation angle. In fact, extensive ground clutter may severely contaminate this product, creating the illusion of intense storms where nothing exists. This occurrence is common when superrefractive conditions are present. Figure 2-37 is an example of the Composite Reflectivity product.

Vertically Integrated Liquid (VIL) Product

Most WSR-88D products emphasize a target's horizontal details. The Vertically Integrated Liquid (VIL) product provides an estimate of atmospheric liquid-water content in the **vertical.** It serves a multitude of purposes, but is primarily designed to evaluate storm severity.

The VIL product is compiled from extensive reanalysis of base reflectivity data. It totals reflectivity within a given column of the atmosphere and then displays a product of tallied values. The function of the VIL algorithm is to estimate the amount of liquid water contained in a storm, and then display that value (kilograms/meter squared) in a graphical form. In its initial stages, the VIL algorithm holds many similarities to composite reflectivity. It builds a volumetric product by compiling reflectivity data from all elevation angles. The difference is that VIL displays tallied values for the entire column (fig. 2-38). CR displays only the reflectivity maxima regardless of altitude. Users can quickly evaluate storms by comparing VIL columns.

VIL is useful when monitoring general echo patterns for signs of development. In convective situations, VIL is directly related to updraft strength, which translates into storm severity. The VIL, product was designed to distinguish severe from nonsevere storms, but it is also used as a hail indicator (very high dBZs).

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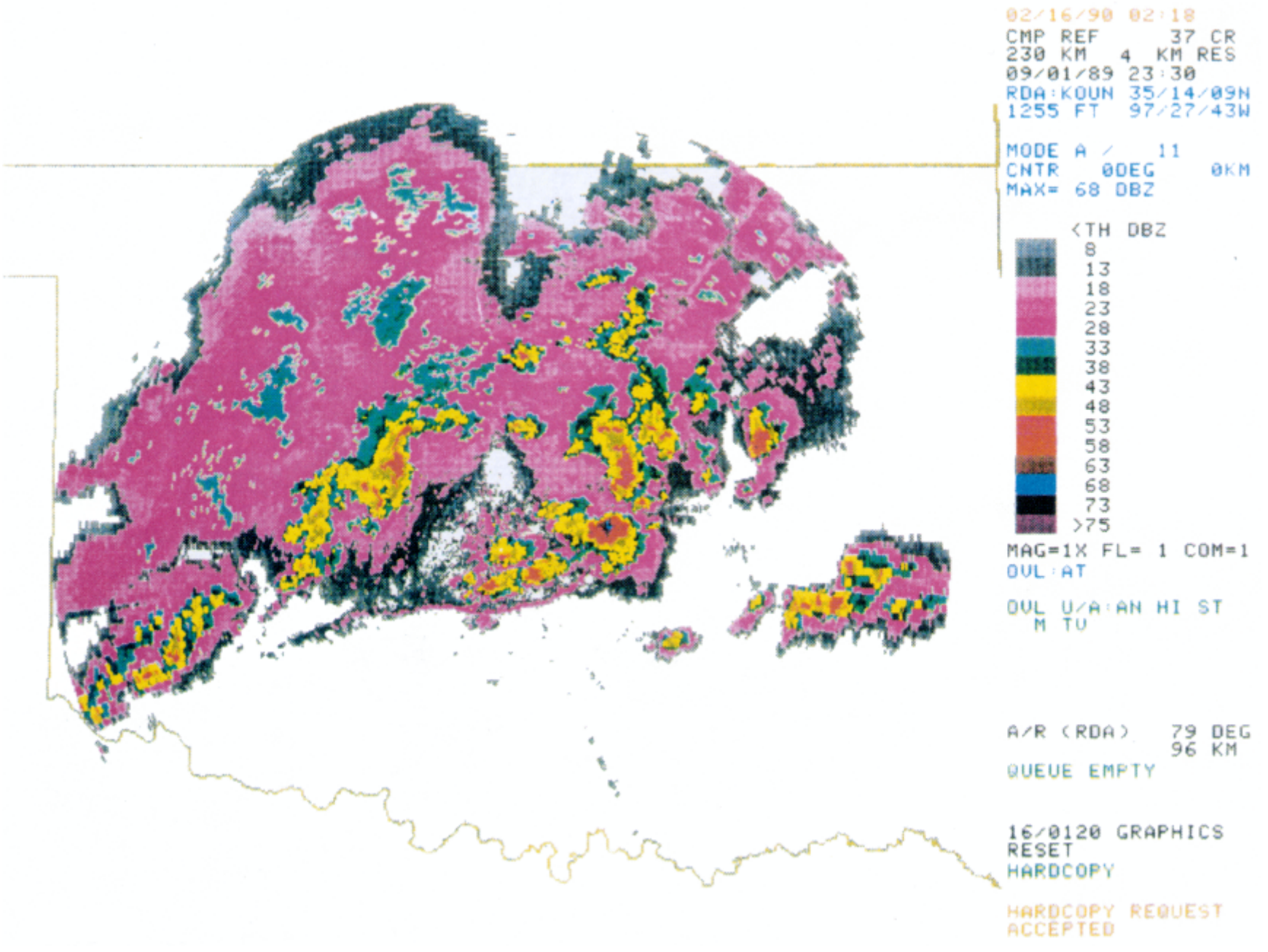

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Figure 2-37.—Composite Reflectivity (CR) product.

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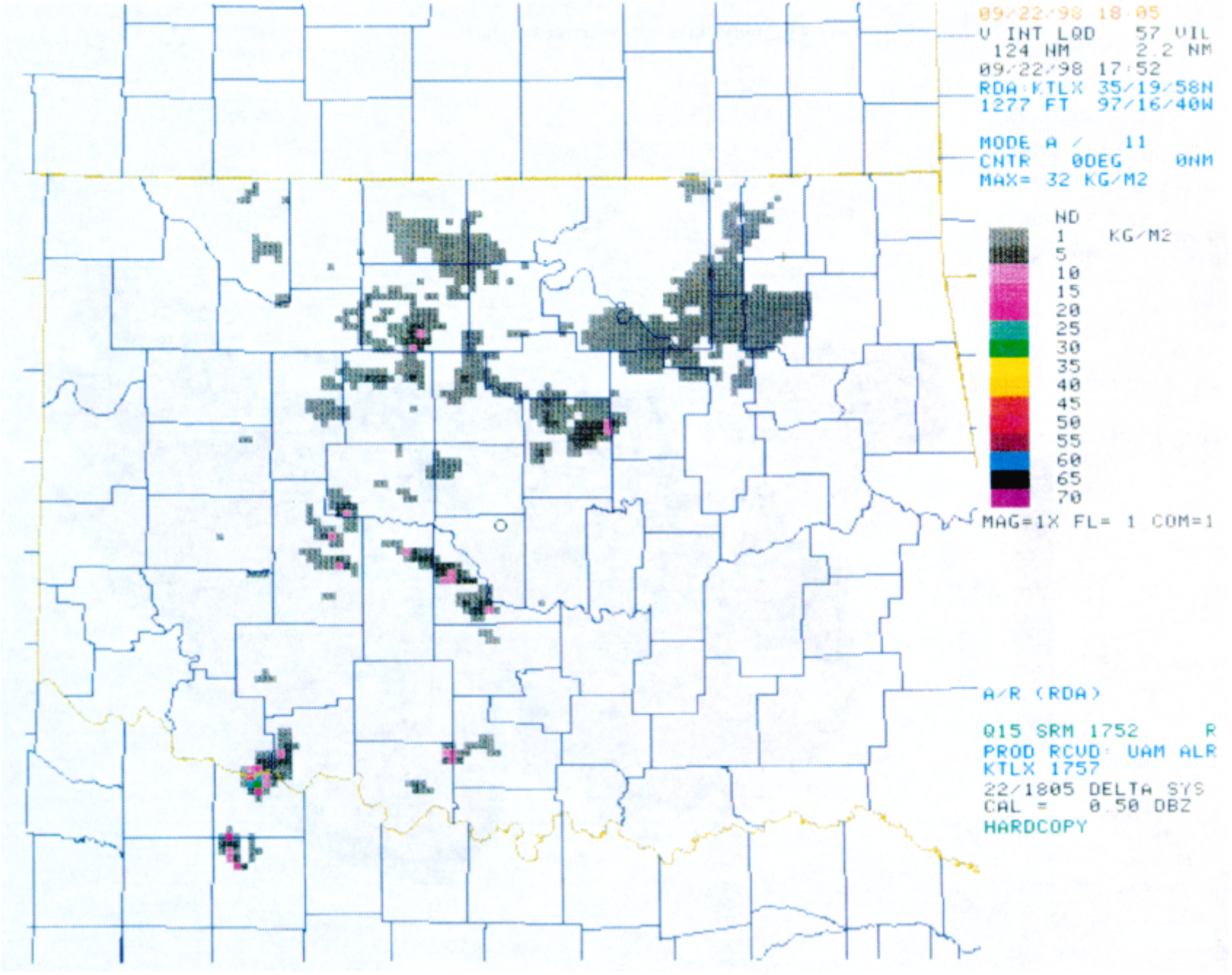

Figure 2-38.—Velocity Integrated Liquid (VIL) product.

VIL values will change with the seasons and from location to location. For instance, warm, moist air masses exhibit higher VIL values during severe weather occurrences than cooler, dry air masses do. Therefore, the product must be tailored to the area of interest. In addition, strongly tilted or fast-moving storms may produce unrepresentative VIL values.

VAD Wind Profile (VWP) Product

One of the most useful and unique products generated by the WSR-88D is the VAD Wind Profile (VWP). VAD stands for velocity/azimuth display, and this program produces current upper wind information on a continuous basis. The VAD Wind Profile is like having real-time rawinsonde data at your disposal every few minutes. It shows wind velocities at various altitudes above the earth in l,000-foot increments, up to 70,000 feet (fig. 2-39).

VWP provides easy-to-read climb winds for pilot briefings. The wind plots of VWP are similar to the wind plots on the Skew-T diagram and are updated each volume scan. VWP depicts environmental flow around the **RDA** and provides valuable insight into general circulation patterns. Be aware that changes in the vertical wind profile are clues to the location of turbulence, inversions, boundary layers, and shear. They're also helpful in determining frontal slope, thermal advection, and the evolution of jet streams.

Different colors are used to indicate the reliability of the wind data. For instance, green wind barbs indicate that plenty of scatterers were available at that particular azimuth and elevation, thus highly accurate wind values are displayed. VWP is unique in that the mere absence of data (plotted as "ND") can itself be an indicator. It suggests fewer scatterers, which implies dryer air (common behind cold fronts). This same technique also allows operators to view changes in overall cloud coverage above the radar's viewing area.

REVIEW QUESTIONS

Q56. Products from the WSR-88D are grouped into what three areas of application?

Q57. What is the purpose of the Routine Product Set (RPS) list?

Q58. What is the purpose of an alert-paired product?

Q59. What does the Base Reflectivity product (REF) display?

Q60. A hook echo signature is associated with what phenomena?

Q61. What does the color blue represent on the Base Velocity product (VEL)?

Q62. Velocities from the Base Velocity product (VEL) are relative to what major component of the WSR-88D?

Q63. What is the most serious drawback to the Composite Reflectivity (CR) product?

Q64. What is the primary purpose of the Vertical Integrated Liquid (VIL) product?

Q65. What might a lack of data indicate when using the VAD Wind Profile (VWP) product?

Echo Tops (ET) Product

Echo Tops (ET) is yet another specialty product derived from base reflectivity. Its simplistic display makes for easy interpretation, but also limits the product's usefulness.

The ET product indicates heights of echoes, in hundreds of feet above mean sea level (MSL). The ET product shows only the highest echoes over a given location and uses different colors to represent heights (fig. 2-40). Targets returning less than 18.0 dBZ (clouds) are completely omitted from the display. ET provides forecasters with a valuable "first look" tool. It allows them to monitor the highest echo tops throughout the radar viewing area. Echo heights paint a very good picture of current weather and make excellent indicators of things to come. For this reason, ET is of particular interest to forecasters and aviators. For example, rapidly increasing echo tops might warn of storm intensification, while decreasing tops indicate weakening. A rapid collapse of echo tops may indicate the onset of downburst conditions at the surface. Other products should be used for additional guidance in understanding the cause of such changes.

The ET algorithm does not tally a column's reflectivity like VIL, nor does it depict the strongest returns like CR. ET merely depicts the highest echoes observed. The ET product can also be deceiving. Plotted heights are not actual cloud tops, but rather the tops of **precipitation.** The clouds themselves are probably less than 18.0 dBZ, and thus extend well beyond the ET heights.

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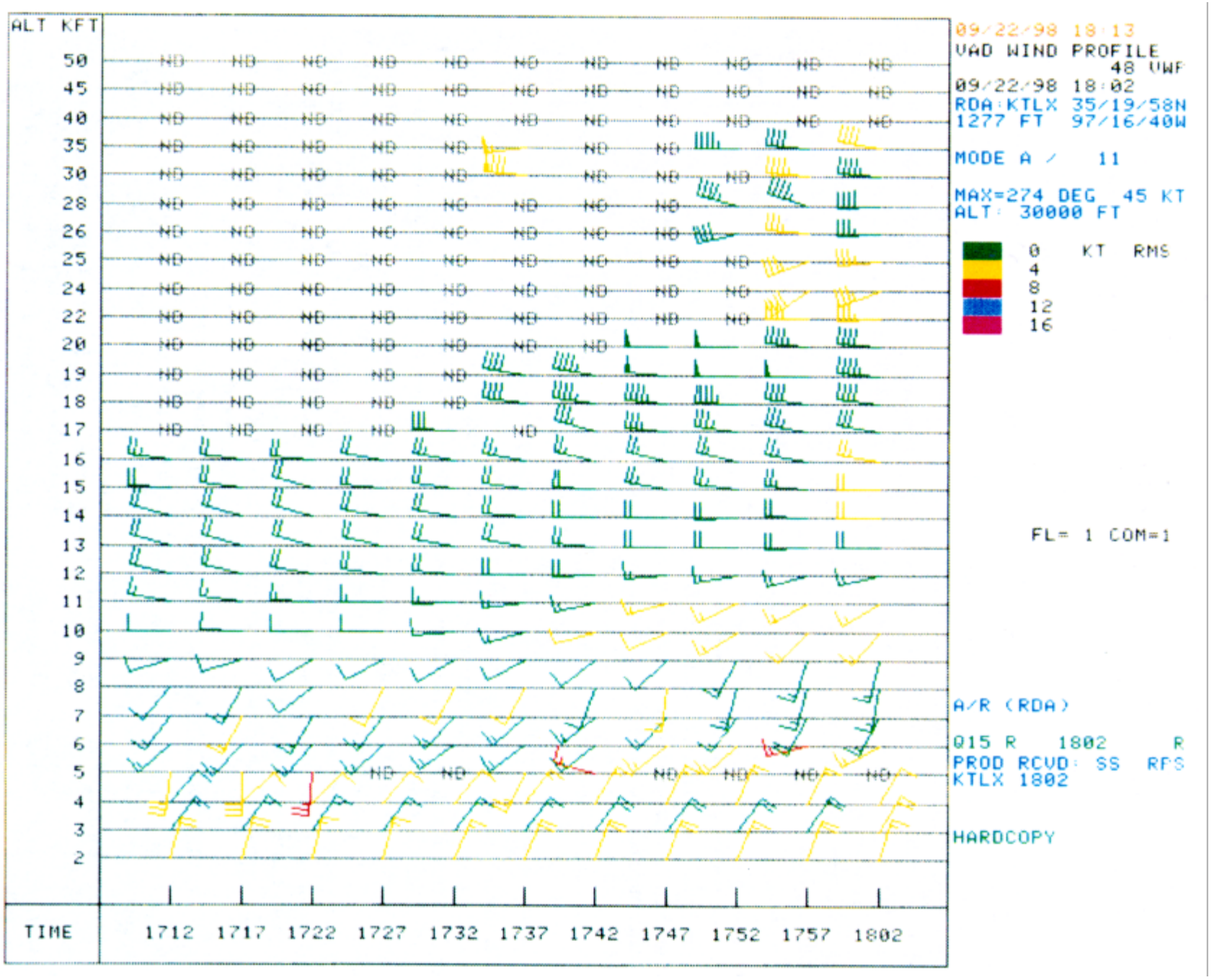

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Figure 2-39.—VAD Wind Profile (VWP) product.

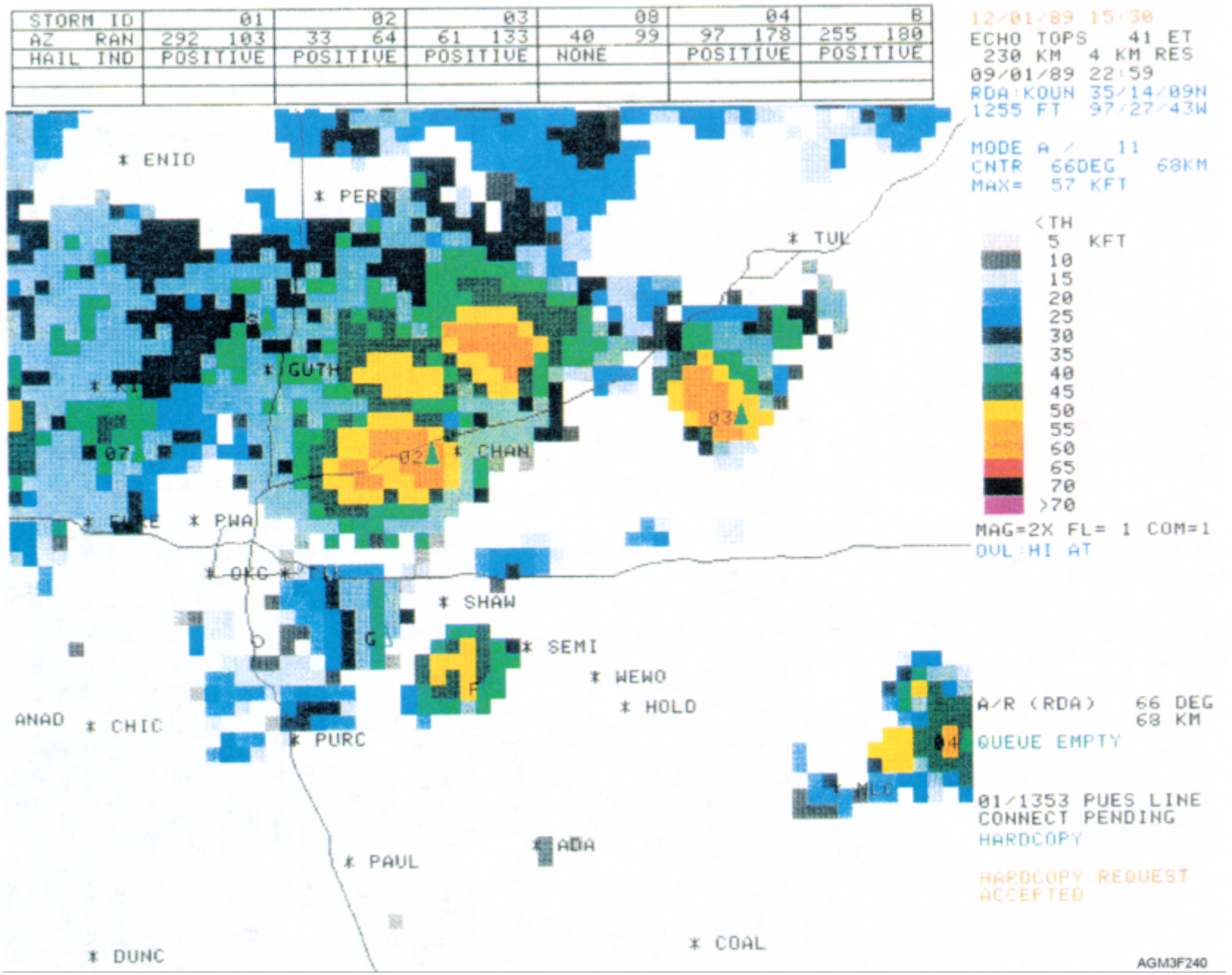

Figure 2-40.—Echo Tops (ET) product.

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Severe Weather Probability (SWP) Product

The Severe Weather Probability (SWP) product provides an objective assessment of each storm's potential to produce severe weather. Unfortunately, its sole input is VIL, and inaccuracies in VIL values will affect the SWP output. Like VIL, SWP is a volumetric product that uses vertically stacked grids to calculate severe potential. Why then would SWP be any better than VIL? SWP grid boxes are much larger than VIL (24.2 x 24.2 nmi). Each SWP box contains 121 VIL grids. Since SWP analyses more area, it builds a larger, more reliable picture of each storm and is less likely to miss or underestimate them.

SWP automatically extracts strong convective cells from current reflectivity patterns and estimates their probability to produce severe weather. Each convective cell is assigned a number that represents the probability that the cell will develop into a severe storm within 30 minutes. By assigning percentage values, SWP draws the user's attention to these dangerous cells and provides an objective tool for evaluating them. SWP can be displayed alone, but is best used as an overlay on other products, perhaps VIL or Base Reflectivity (REF). Figure 2-41 is an example of the Severe Weather Probability product.

SWP data is calculated from VIL and ultimately base reflectivity. Therefore, SWPs are affected by all of the same factors that affect VIL and REF.

Mesocyclone (MESO) Product

Mesocyclones are areas of strong cyclonic rotation found in supercell thunderstorms. Such storms are normally accompanied by severe weather, although not all mesocyclones produce tornadoes.

The WSR-88D uses extensive computer processing of velocity data to build an extremely valuable product called MESO (mesocyclone). The algorithm continuously searches for rotating wind fields produced by areas of strong shear. Shear is a speed and/or directional variation in the wind field with height. The algorithm is designed to identify three types of shear and categorize them accordingly; 2-D shear, 3-D shear, or mesocyclone.

2-D SHEAR.—This is an area of horizontal rotation that meets the algorithm's shear and symmetry tests. Symmetry determines the area's balance and uniformity. 2-D shear lacks vertical consistency. It is only found at one elevation angle and cannot be linked at adjacent levels. For this reason, 2-D shear is said to be "uncorrelated" shear.

3-D SHEAR.—3-D shear has vertical consistency and can be linked to other elevations. However, 3-D shear fails the symmetry tests required for mesocyclone classification. The shear area is not balanced or uniform. 3-D shear is termed "correlated" shear because of its vertical link.

MESOCYCLONE.—This category identifies shear regions that meet all algorithm requirements of size, shape, symmetry, and vertical consistency associated with a mesocyclone.

MESO, like any product, is just a tool. It should NEVER be used as a stand-alone source of information, and its findings should always be confirmed with other products such as VEL. Although velocity data is processed up to 124 nmi from the RDA, the optimum effective range of this product is severely restricted by beam broadening. The mesocyclone detection algorithm does not establish time continuity; this is left up to the operator. Figure 2-42 is an example of the MESO product. It indicates that a single mesocyclone (large circle) has been identified just northwest of the station.

Tornadic Vortex Signature (TVS) Product

Just as with the MESO product, the Tornadic Vortex Signature (TVS) algorithm performs extensive reanalysis of base velocity data to build each TVS product. This product is designed to search out tornadic signatures within mesocyclone bearing storms.

The TVS product is a small area of abnormally high shear commonly associated with tornadoes. Like mesocyclones, TVSs are first detected at the storm's mid-section and grow, both up and downward, with time. They reach cloud bases coincident with the appearance of a funnel cloud (as viewed from below). Studies suggest that TVSs are detectable 20 minutes prior to tornado touchdown (on average). Most TVSs detected by the WSR-88D are associated with tornadoes. However, not all tornadoes produce a TVS. Like the mesocyclone product, TVSs primary function is to alert users of high rotation and shear. An area with possible tornadic activity is indicated by an inverted

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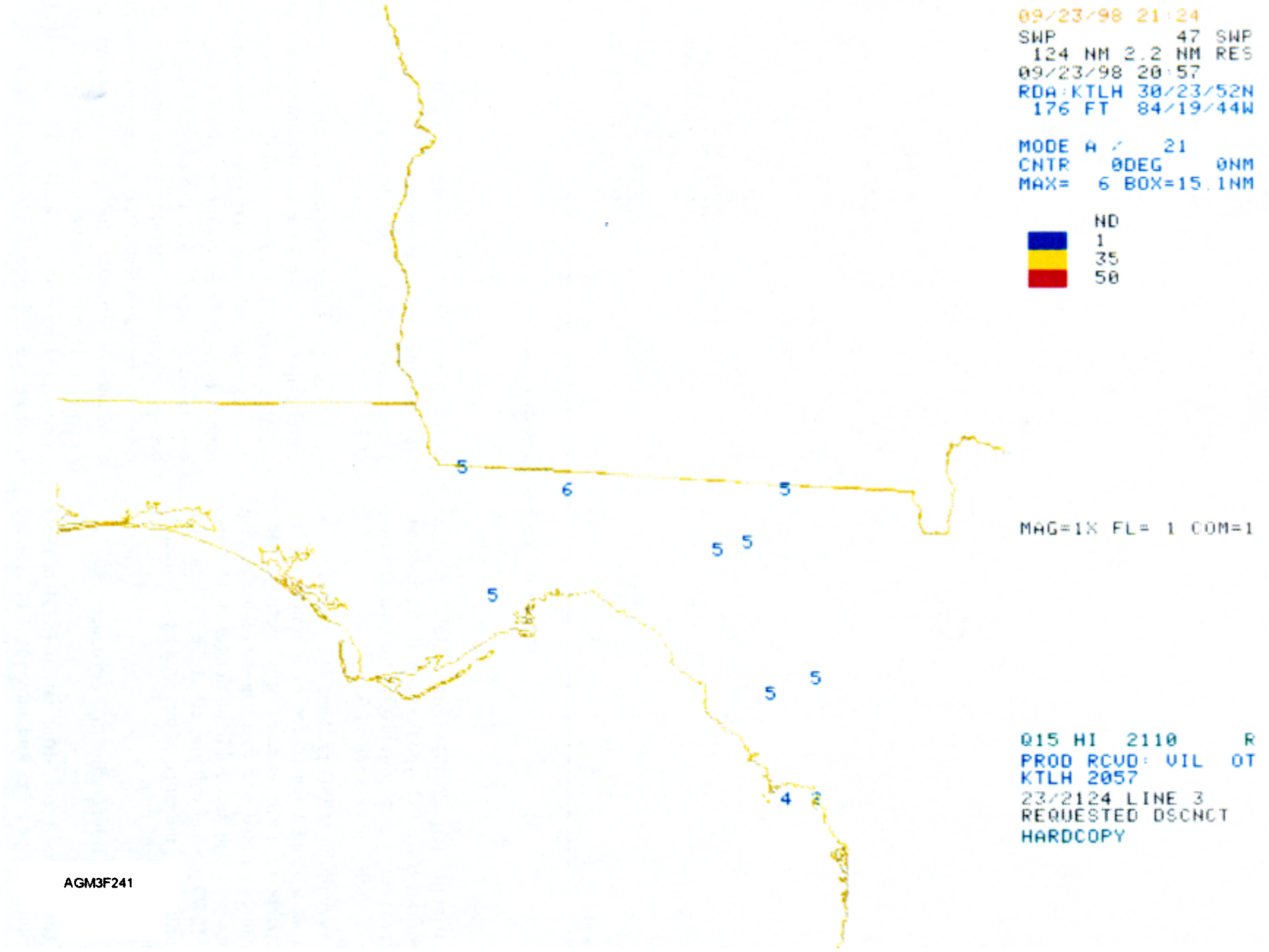

Figure 2-41.—Severe Weather Probability product.

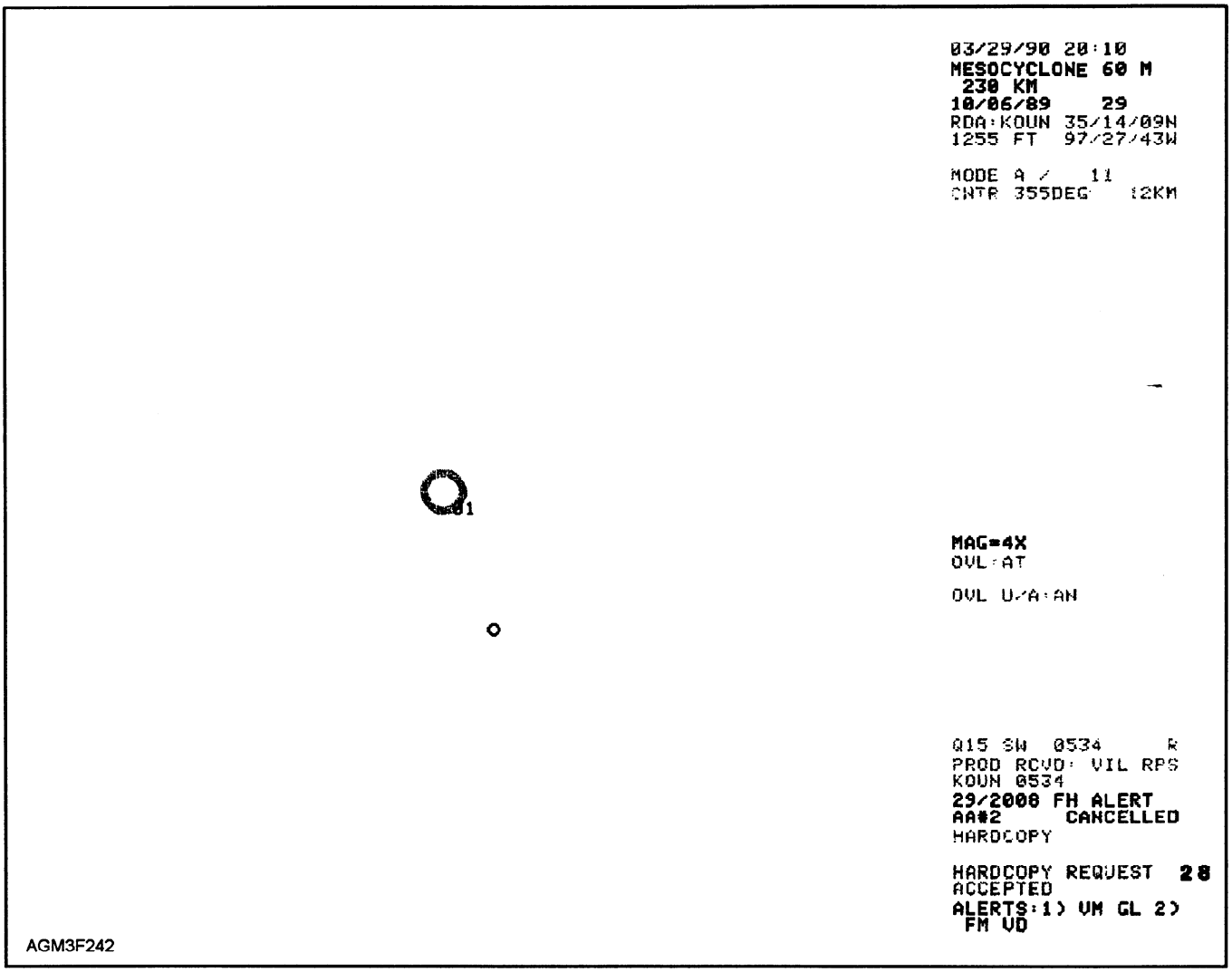

Figure 2-42.—Mesocyclone (MESO) product.

red triangle (fig. 2-43). Immediately upon the identification of a TVS, you should notify the forecaster and turn your attention toward other products for further investigation (e.g. base velocity).

As with the MESO product, TVS should not be used as a stand-alone source of information. The algorithm of TVS searches only mesocyclones. Tornadoes formed outside of mesocyclone bearing storms go undetected. All limitations associated with the MESO product will also effect the TVS product. Unfortunately, the range of this product is limited to approximately 60 nmi.

Storm Track Information (STI) Product

The Storm Track Information (STI) product monitors the position and movement of isolated thunderstorms within a 250-nmi radius of the RDA. It also estimates future movement of isolated storms. These forecasts can be used to generate automated alerts.

STI monitors the movement of isolated storms by correlating each storm's current position to a storm found in the previous volume scan. These storms are then related to each other in time and space. If a storm cannot be correlated to the previous scan, it is designated as "new." STI also provides users with best-guess guidance on storm paths throughout the radar coverage area. Each storm is assigned a unique alphanumeric identifier (fig 2-44). Movements are forecast in 15-minute increments, for up to 1 hour (represented by each tic mark). The algorithm's internal confidence factor rates each storm

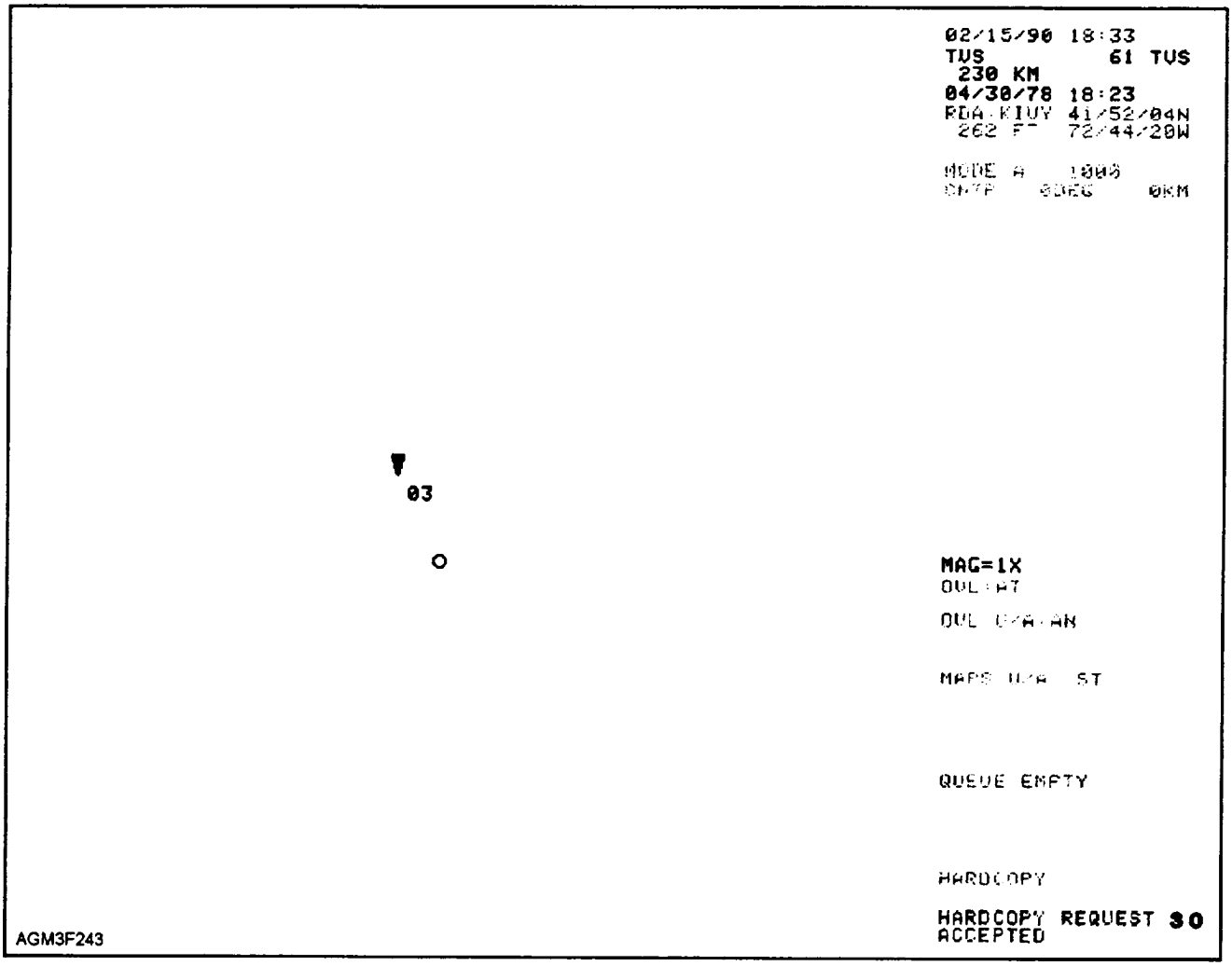

Figure 2-43.—Tornadic Vortex Signature (TVS) product.

independently and determines whether the product will forecast an entire hour's movement, a 45-, 30-, or 15-minute movement, or simply omit a forecast for any given storm. Up to 100 storms may be monitored simultaneously.

If a storm's motion exceeds certain thresholds, the STI algorithm may become confused. It bases forecasts on linear extrapolation of past movement. Therefore, storms traveling in a curved path or changing direction will not be accurately forecast. STI is intended for well-defined, isolated thunderstorms. Under any other circumstance (i.e., squall lines, LEWPs, etc.) the algorithm becomes confused, resulting in a questionable product. If storms have crossing paths, or are in close proximity to one another, the algorithm might misidentify them and in extreme cases, identify them as a single storm.

Hail Index (HI) Product

The Hail Index (HI) product scans all storms within the radar coverage area and searches for very high reflectivity values located above the freezing level. It then provides an indication of which storms are expected to produce hail. All storms are examined for hail potential, then categorized accordingly. While the algorithm is not foolproof, it provides a valuable first guess. The hail product provides estimates on the probability of hail, probability of severe hail, and maximum expected hail size. The hail product provides an extremely simple display, making it a good overlay for other products. As you can see in figure

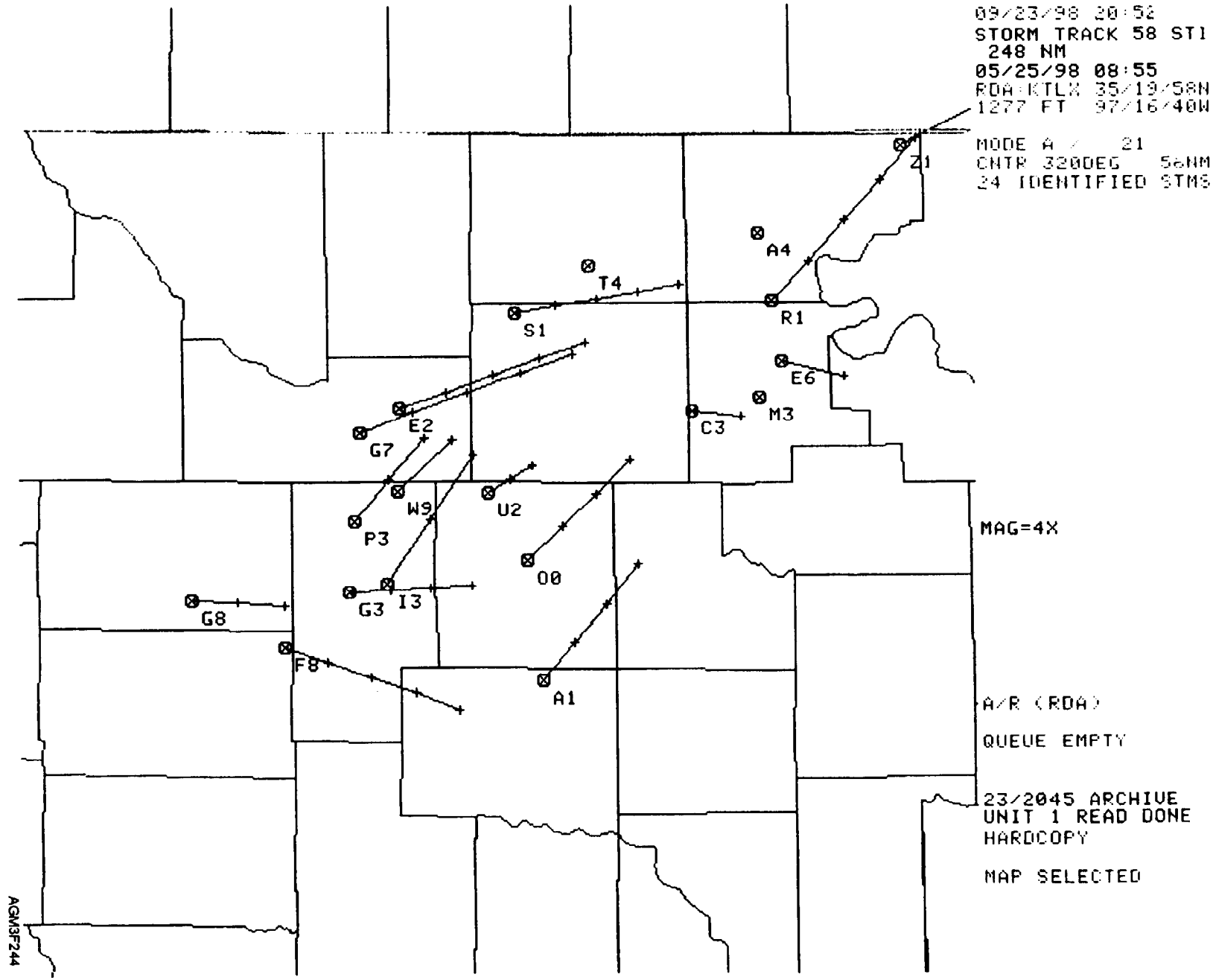

Figure 2-44.—Storm Track Information (STI) product.

2-45, each storm is assigned a unique alphanumeric identifier. The small green triangles that are not filled in indicate the probability of hail of any size within that particular storm. The small green filled triangles indicate the probability of hail equal to or greater than 3/4 of an inch. The numbers inside the larger green triangles indicate maximum expected hail size to the nearest whole inch. In any case, the Hail Index product quickly indicates the possibility of severe weather in the radar coverage area.

Hail is a volumetric product, therefore, it is only available at the end of a volume scan. It requires input from several sources, and contamination at any level results in a loss of the product. While the hail product is nice to have, it should be routinely verified using VIL and VEL.

Reflectivity Cross-Section (RCS) Product

Cross sections provide a unique perspective of the atmosphere. They create an illusion that places you, the operator, into the heart of a target. This allows you to view meteorological targets, such as mesocyclones, from the inside. Cross-section products can be built from any of three radar moments (reflectivity, velocity, and spectrum width) and are primarily used to examine vertical storm structure. All cross-section products operate on essentially the same principle. That is, they allow a vertical depiction of the atmosphere by compiling base data vertically, along a user-defined direction. Data from a cross-section product is presented in a range (up to 124 nmi) versus height (up to 70,000 feet) format.

The Reflectivity Cross-Section (RCS) product is helpful even during nonconvective events. The depth of moist layers can be determined by the vertical extent (thickness) of scatterers. When cross sections are cut across frontal boundaries, frontal slope can be determined. For observing purposes, RCS is a good tool for measuring cloud bases and tops, and inversion boundaries. Clouds generally appear as well-defined layers, with a significant decrease in energy (dBZs) at the cloud‘s edge. Of course, RSC is very useful when evaluating severe weather potential. It permits three-dimensional analysis of storm dynamics and lets you determine the extensiveness or depth of a given feature. RCS is also an excellent product for locating WERs, BWERs, and maximum reflectivity cores. Figure 2-46 is an example of the RCS product.

The selection and placement of the cross section is extremely important. Even slight deviations often result in misanalysis of anticipated features (hooks, BWER, etc.). Also be aware that targets displayed by RCS are not always meteorological, but may be the result of birds, insects, etc.

Velocity Cross-Section (VCS) Product

When it comes to storm interrogation, no analysis is complete without a thorough look at velocity data. The Velocity Cross-Section (VCS) product provides a vertical cross section of velocity data. It is available in two different modes; clear-air and precipitation.

In clear-air mode (mode A), the Vertical Cross-Section (VCS) product can determine the existence and depth of turbulent layers and determine the intensity of wind shear. Boundaries and frontal slopes are evident by significant changes in wind speed or direction. These features are often more visible here rather than on an RCS product. In precipitation mode (mode B), the existence, strength, and vertical depth of vortices (areas of rotation) are analyzed. These may confirm the presence of mesocyclones or tornadoes and make a strong case for severe weather when linked to other products. VCS is an excellent tool for determining divergence, convergence, and cyclonic and anticyclonic rotation. Figure 2-47 is an example of the Velocity Cross-Section product.

The limitations of this product are similar to the Reflectivity Cross-Section product. Keep in mind that the plane along which the cross section is built MUST be either parallel or perpendicular to the radar viewing direction. If the cross section is cut at any other angle, you are viewing the radial component of radial velocities. This makes the data extremely hard to interpret.

RADAR CODED MESSAGES

The Radar Coded Message is a high-resolution product that provides summary radar information. It is primarily used in the preparation of the National Radar Summary Chart. The message is composed of three parts. Part A is a reflectivity graphic product that is automatically generated by the system. The local grid at each antenna site is designed to become part of the national radar grid. Part B contains a single profile of the horizontal wind information derived from the output of the Velocity Azimuth Display (VAD) algorithm. It is also produced automatically and is presented to the user as an alphanumeric message. Part C contains remarks in an alphanumeric format. Remarks, such as tornadic vortex signatures,

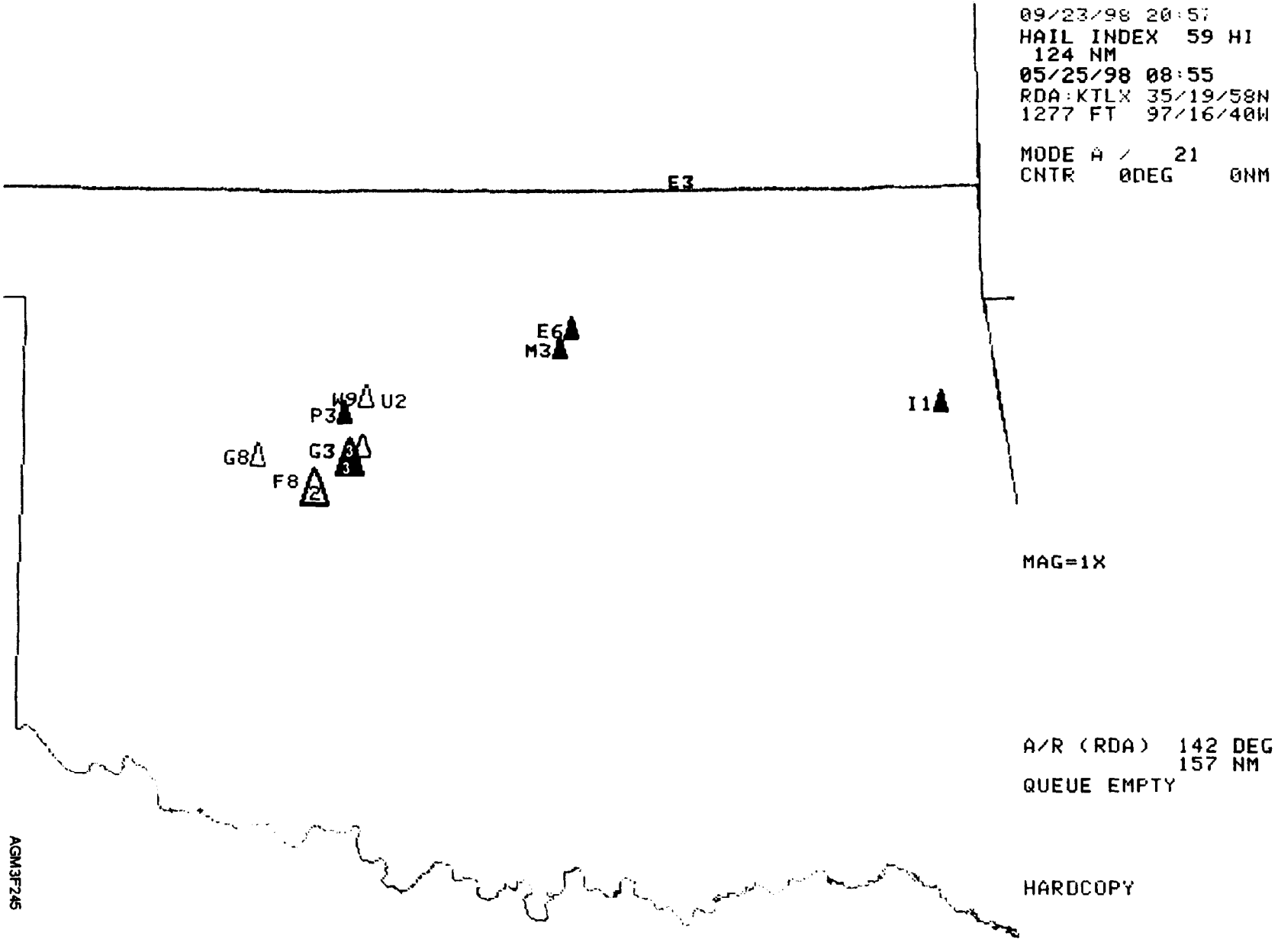

Figure 2-45.—Hail Index (HI) product.

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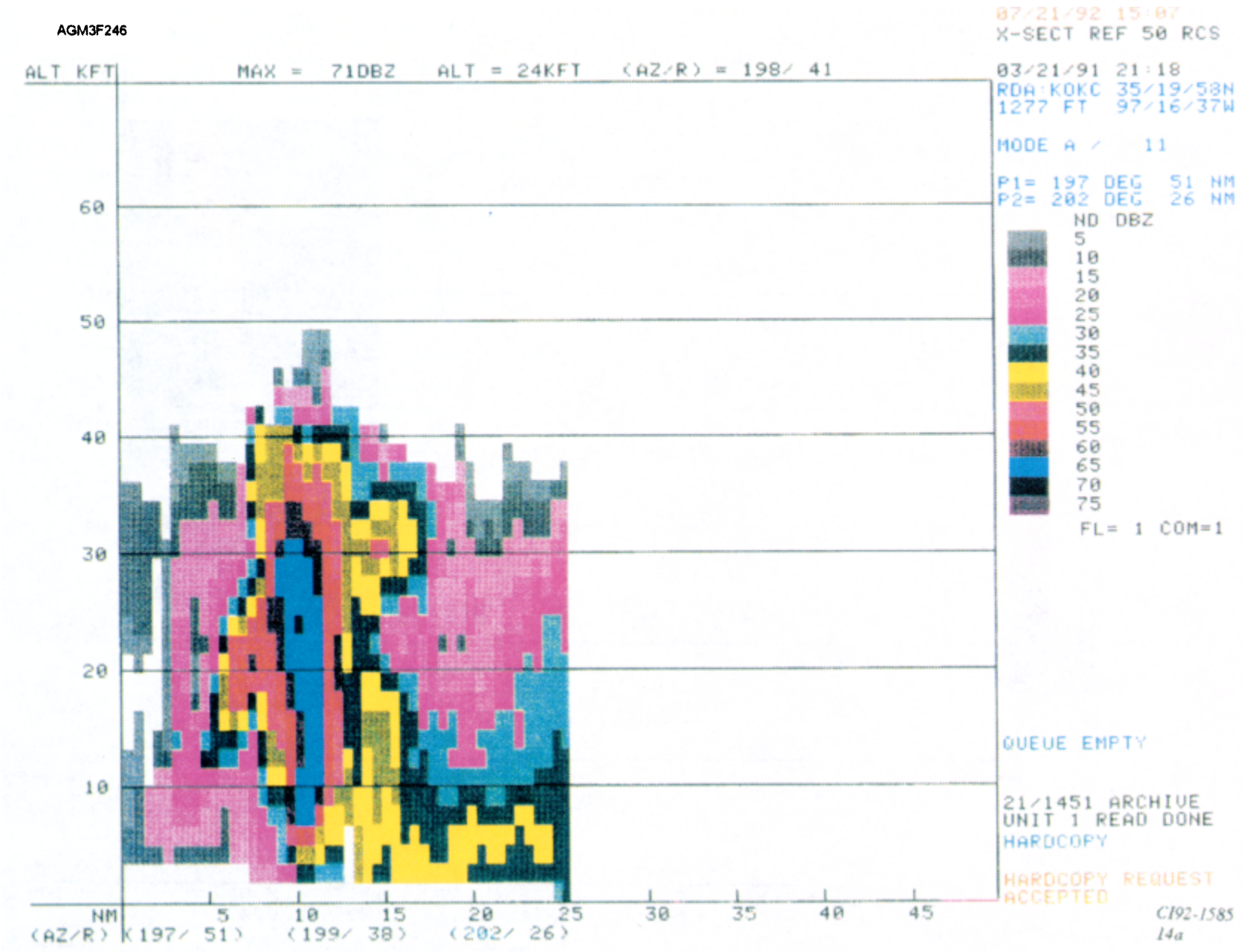

Figure 2-46.—Reflectivity Cross-Section (RCS) product.

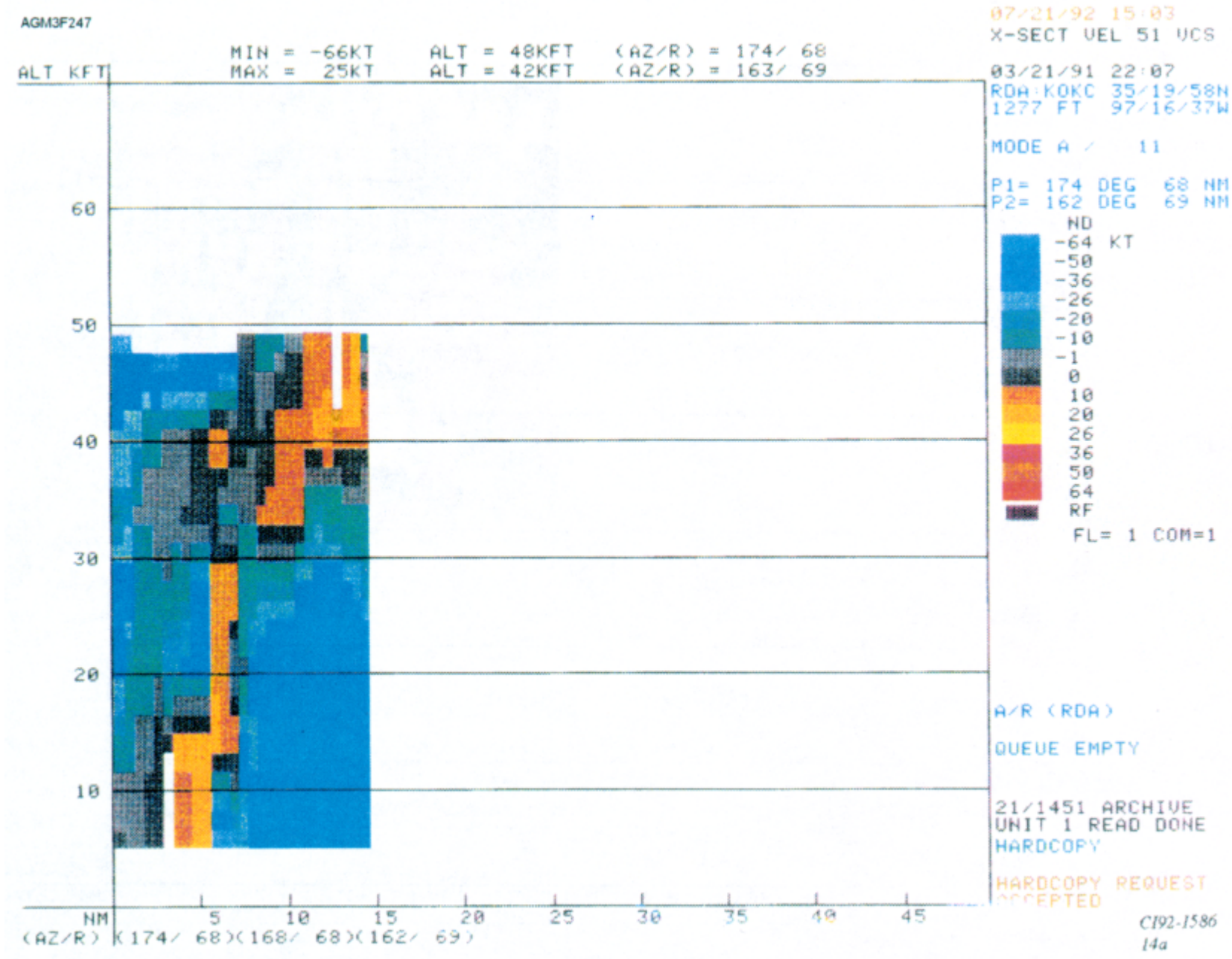

Figure 2-47.—Velocity Cross-Section (VCS) product.

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mesocyclones, centroids, storm tops, and hail indices are all automatically generated. In addition to the automatically generated remarks, Part C provides for optional manual entries. Appendix III provides a listing of definitions and symbols that are routinely used in the remarks section.

REVIEW QUESTIONS

Q66. What do the plotted heights on the Echo Tops (ET) product indicate?

Q67. What is displayed on the Severe Weather Probability (SWP) product?

Q68. What is a mesocyclone?

Q69. The Tornadic Vortex Signature (TVS) product is derived from what data?

Q70. How long will the Storm Track Indicator (STI) product track an individual storm?

Q71. What information does the Hail Index (HI) product provide?

Q72. What is the primary purpose of the Reflectivity Cross-section (RCS) product?

Q73. How could the Reflectivity Cross-Section (RCS) product be useful to an observer?

Q74. What information can be obtained from the Vertical Cross-Section (VCS) product in clear-air mode?

Q75. What does the symbol "ZR " indicate in a Radar Coded Message?

WSR-88D PUBLICATIONS

LEARNING OBJECTIVE: Identify the publications associated with the WSR-88D system.

The Federal Meteorological Handbook No. 11 (FMH-11), *Doppler Radar Meteorological Observations,* is the governing manual for Doppler weather radar observations and consists of four parts. Part A, *System Concepts, Responsibilities. and Procedures,* explains the overall concept of the WSR-88D program and details site responsibilities and outlines general procedures. It also contains default values for the WSR-88D. Part B, *Doppler Radar Theory and Meteorology*, contains a detailed description of the WSR-88D along with a functional overview of system components. It also contains valuable information on the interpretation of Doppler velocity patterns. Part C, *WSR-88D Products and Algorithms,* describes the various products and algorithms of the WSR-88D, and provides information on the different operational modes. Part D, *WSR-88D Unit Description and Operational Applications*, provides an in-depth description of the various components of the WSR-88D and discusses the operational applications of meteorological and non-meteorological echoes.

The *Operator's Handbook, Principal User Processor,* consists of three volumes and is the best guide to learning the operation of the PUP workstation. Volume I contains information on the graphic tablet and Volume II contains information on the applications terminal. Volume III details information on the system console.

SUMMARY

In this chapter, we covered the WSR-88D Doppler weather radar system. We began with a discussion of electromagnetic energy and radar theory. Then we discussed the basic principles of radar propagation and the effects of atmospheric variables on this propagation. We then introduced you to Doppler radar theory and discussed the configuration and communications system of the WSR-88D. We completed the chapter with an overview of the strengths and limitations of the products available from the WSR-88D.

ANSWERS TO REVIEW QUESTIONS

A1. An electromagnetic wave is radiation energy in the form of a sine wave with both electrical and magnetic properties.

A2. Radio (microwave) region.

A3. Centimeters or degrees.

A4. Shorter wavelengths provide finer detail. Longer wavelengths are more effective when evaluating larger targets.

A5. Frequency is the number of completed wave cycles per second, measured in hertz.

A6. 100 GHz.

A7. By using the decibel system.

A8. Reflectivity is the amount of energy returned from an object and is dependent on the size, shape, and composition of the object.

A9. The antenna.

A10. The sensitivity of a radar is the measure of the radar's internal interference against the minimum signal it is designed to detect.

A11. Longer pulses return more power, thus increased target information and data reliability.

A12. In seconads or kilometers.

A13. Resolution refers to the ability of the radar to display multiple targets clearly and separately.

A14. The rate at which pulses are transmitted per second.

A15. An increase in PRF provides greater target detail; however, the maximum range of the radar is reduced.

A16. The inability of the radar to distinguish between return pulses, producing ambiguous (unreliable) range information.

A17. 93 miles (81 nmi).

A18. A pulse from a distance outside the radar's normal range returns during the next pulse's listening time, causing confusion.

A19. As the pulse moves away from the radar, volume expands and power density decreases.

A20. The smaller beam.

A21. Beam broadening increases pulse volume resulting in decreased signal strength.

A22. The presence of sidelobes leads to confusion in interpreting targets because short-range, non-meteorological targets are displayed along with main beam targets.

A23. An increase in beamwidth or target distance.

A24. Pulse length.

A25. The bending of (electromagnetic) waves.

A26. Moisture.

A27. N-units normally decrease with height.

A28. Subrefraction.

A29. A strong inversion,

A30. The existence of buildings, trees, or rough terrain near the radar antenna.

A31. Backscattering.

A32. Absorbers are mainly oxygen and water vapor.

A33. A means to measure motion.

A34. The outstanding capabilities of the WSR-88D include velocity detection, increased power and sensitivity, and the integration of high tech computers.

A35. It increases.

A36. A phase shaft is an observable repositioning of a point on a wave between successive transmissions.

A37. In degrees.

A38. By measuring phase shift, wavelength, and the time interval between pulses.

A39. As a target moves more perpendicular to a radar, the velocity detected becomes less than the true velocity.

A40. Velocity aliasing is a process that causes a Doppler radar to display untrue velocities because of the motion of the target.

A41. The Nyquist velocity is the maximum unambiguous velocity that can be detected at any given pulse repetition frequency (PRF).

A42. 29.4 mps (57 knots).

A43. Velocity aliasing and range folding.

A44. Radar Data Acquisition (RDA).

A45. Hail.

A46. Ground clutter and range folding.

A47. The Radar Product Generator (RPG).

A48. Base products are near real-time displays and are available after each scan. Derived products are base products that have been modified or enhanced to produce special results.

A49. Principal User Processor (PUP).

A50. A graphic tablet and puck

A51. Associated Principal Users (APUPs).

A52. Dedicated telephone lines.

A53. Archive Level IV

A54. A volumetric product requires the entire volume of radar coverage (all elevation angles) to be scanned.

A55. Mode A, VCP 11.

A56. Precipitation measurement, storm warnings, and wind profiling.

A57. The RPS provides an automated way of managing RPG workload and allows users to identify and access up to 20 routinely required products.

A58. Alert-paired products are transmitted whenever criteria for severe weather is met. They are sent in conjunction with an alert message.

A59. Reflectivity values from scatterers in the radars viewing area.

A60. Tornadoes.

A61. Velocities moving toward the radar (negative values).

A62. The RDA.

A63. Lack of target height information.

A64. To display an estimate of the atmosphere's liquid water vapor content in the vertical.

A65. Few scatterers in the atmosphere, thus drier air.

A66. Precipitation.

A67. The Severe Weather Probability (SWP) product displays only strong convective cells and assigns percentage values based on each cell's chances of producing severe weather.

A68. A mesocyclone is an area of strong cyclonic rotation found in supercell thunderstorms.

A69. Base velocity

A70. One hour.

A71. The Hail Index product provides estimates on the probability of hail, the probability of severe hail, and the maximum expected hail size.

A72. To view meteorological targets in the vertical (from the side).

A73. The observer can determine cloud layer height and inversion layer height.

A74. Depth of turbulent layers, wind shear intensity, boundaries and frontal slopes.

A75. Freezing rain.